dialogue on water and climate

Coping with Impacts of Climate Variability and Climate Change in Water Management: A Scoping Paper

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Colophon

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Preface

The International Dialogue on Water and Climate (DWC) is a platform that bridges the information gaps between the water and climate sectors in order to improve our capacity to cope with the impacts on water management of increasing climate variability and change. The goal of the Dialogue is to develop a knowledge base, generate widespread awareness, identify policy and management options that build such capacities, learn from the experiences throughout the world, and make this knowledge available to the most affected communities.

At a meeting in Delft in the Netherlands in November 2001, about 50 hydrologists, climate scientists and water managers discussed climate change and climate variability in relation to Integrated Water Resource Management (IWRM) at the initiative of the DWC. A summary of the most important outcomes and recommendations is reflected in this document. These outcomes and recommendations were used as the basis for a series of themes and dialogues which were then commissioned by the International Dialogue on Water and Climate for further study (Table 0.1).

In many parts of the world, variability in climatic conditions is already resulting in major impacts. These impacts are wide ranging, and the link to water management problems is obvious and profound. Climate variability is already being observed to be increasing, although there are still large uncertainties about the link to climate change (IPCC, 2001). Floods, droughts and other extreme climate events, such as hurricanes, add to the major problems water managers' face from population growth, urbanisation and land use changes. Every year they inflict severe damage on humans and the environment in many parts of the world, but particularly so in those so-called 'hot spots' where the frequency of occurrence is greater, the sensitivity higher, the devastation more severe or the communities more vulnerable. We can do little to control the timing and intensity of such hazardous events in the short term. Emissions control measures being adopted are, however, likely to help in the long term. What we need to do, and can, is increase our capacity to cope with the extreme climate events, if we increase our knowledge to do so. Anticipated global warming is likely to exacerbate climate variability, and hence hydrological responses. Box 0.1 summarises some of the key issues in relation to climate change and water.

Box 0.1 Key issues in relation to climate and water in Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001)

> "*Climate change will lead to an intensification of the global hydrological cycle and can have major impacts on regional water resources, affecting both ground and surface water supply for domestic and industrial uses, irrigation, hydropower generation, navigation, in-stream ecosystems and water-based recreation. Changes in the total amount of precipitation and in its frequency and intensity directly affect the magnitude and timing of runoff and the intensity of floods and droughts; however, at present, specific regional effects are uncertain".*
>
> *"The impacts of climate change will depend on the baseline condition of the water supply system and the ability of water resource managers to respond not only to climate change but also to population growth and changes in demands, technology, and economic, social and legislative conditions. In some cases - particularly in wealthier countries with integrated water-management systems - improved management may protect water users from climate change at minimal cost; in many others, however, there could be substantial economic, social and environmental costs, particularly in regions that already are water-limited and where there is considerable competition among users.*"

Both present variability and long-term climate change impacts are most severe in the developing world and particularly affect the poor, i.e. the segment of society least able to buffer itself against impacts. The vulnerabilities that climate variability and change create are, in consequence, a key issue in any poverty reduction programme. The impacts are widespread, but there are ‘hot spots’ where they are particularly severe: countries, regions and communities where the capacity to cope with, and adapt to, the hydrological effects of climate variability will influence their overall development prospects.

The implications of climate variability and climate change have not been fully considered in current water policy and decision-making frameworks. This is particularly true in developing countries, where the financial, human and ecological impacts are potentially greatest, and where water resources may be already highly stressed, but the capacity to cope and adapt is weakest.

There are already several regional and international initiatives underway that focus on various aspects of water resources management. By co-operating with these, the Dialogue on Water and Climate has sought to raise greater awareness of the issues relating climate vulnerability to water resources management, and to set in motion a political process designed to bridge policy gaps. The Dialogue itself has different components where the water resource management and climate scientist communities are engaged in a process of building confidence and understanding, identifying options and defining strategies which are applicable at regional, national and river basin levels. The envisaged final outcome are policies and actions that create conditions where more effective coping and adaptation mechanisms for dealing with water and climate vulnerability are developed and applied at the international, national and community levels.

A Summary of Key Issues Addressed in this Document

The most important outcomes and recommendations from the workshop of the International Dialogue on Water and Climate held in Delft in the Netherlands in November 2001 are reflected in this summary. These outcomes and recommendations were used as the basis for a series of themes and dialogues, which were commissioned for further study within framework of DWC (Table 0.1). Furthermore, these outcomes were presented at the launching event of the International Dialogue on Water and Climate during the International Conference on Freshwater in Bonn in December 2001.

Table 0.1 Framework of dialogues and themes of the Dialogue on Water and Climate

THEMES & DIALOGUES	**Science on Water and Climate**	**Adaptation and Coping**	**Institutional and Political Aspects**	**Identifying 'Hot Spots'**	**Knowledge Transfer**
National Dialogues Bangladesh, Russia, The Netherlands	√	√	√	√	√
Basin Dialogues San Juan, San Pedro, Thukela, Lena, Murray-Darling, Yellow River, Nagoya	√	√	√	√	√
Regional Dialogues South Asia, Central America, Caribbean Islands Pacific Islands, West Africa, Southern Africa, Mediterranean	√	√	√	√	√
Themes • Climate Scenarios and Uncertainties	√	√			
• Floods		√		√	
• Droughts		√			
• Sea level rise				√	
• Groundwater		√	√	√	
• Lakes	√				
• Ecosystems	√	√			
• Dams and hydropower	√	√			
• Hot Spots	√				
• Mega Cities			√		
• Health		√	√		√
• Forecasting		√	√		
• Insurance		√	√	√	
• International conventions	√	√			
• Social and cultural aspects in relation to coping with disasters	√	√			
• Poverty		√	√		
• Institutions		√	√		√
• Philosophies	√				
• Economic Indicators in Africa		√		√	
Case/desk studies • Brazil	√		√		√
• Venezuela	√	√			√
• Food, water and Climate (ADAPT)	√	√		√	
• Aral Sea	√	√			
• American Isthmus		√			√
Tools • Education and Training		√			√
• E-Atlas	√				√
• Global Analysis	√			√	

√ = An issue that is considered part of a theme or dialogue
A cell in Table 0.1 is shaded grey if the study is focussing strongly on this subject

What are the implications of climate variability and change on water resources?

- There is increasing evidence that climate is becoming more variable. However, there remain large uncertainties as to whether this may be attributable to global warming. Increasing climate variability may lead to an intensification of the hydrological cycle. For some regions increases in magnitudes and frequencies of extreme events are already being observed. In addition there is a possibility that future extremes are projected to be even more severe than those experienced to date.

- Climate change, as well as increases in climate variability, will increase the vulnerability of certain regions and communities to changes in hydrological responses. Foresighted management practices will be needed to help cope with, and adapt to, these changes.

- Climate variability and change have been identified as key drivers of ecosystem health and the growth and spreading of water-related diseases.

- The good news is that coping for present-day climate variability in water resources already takes us a long way down the road towards coping for any further impacts of climate change. However, coping with climate variability is, in itself, already a formidable challenge.

What can be done in water management to cope with, and adapt to, climate variability and change?

- There is an impressive array of specific management measures, both structural and non-structural, that water managers already use routinely to accommodate present-day climate variability. These will also serve towards adaptation to any impacts of enhanced climate variability and climate change. However, a single and universal adaptation approach or remedy, does not exist.

- In order to ensure that these tools be applied appropriately, a ‘no regrets’ approach to water resources planning and management is necessary. In particular, in light of climate change uncertainties, the application of the precautionary principle to water resources management should be promoted.

- The expected impacts on water resources should be neither under- nor overestimated, but should be assessed in a scientifically rigorous and realistic manner. Only then can management decisions and appropriate adaptation strategies be formulated.

- Small islands and coastal zones are highly threatened by both extreme events and sea level rise. Although not addressed explicitly in this document, the irreversibility of sea level rise during our lifetime and in future generations implies that adaptation is the only option in those regions.

- IWRM and Integrated Coastal Zone Management (ICZM) are prerequisites for adapting to present-day climate variability. They encompass a wide range of accepted water management practices that will readily serve adaptation to climate change.

- In addition to IWRM and ICZM, a paradigm shift is required in water management strategies towards 'living with floods and droughts'.

- Although results from long-term climate projections are, as yet, too uncertain and varying to meet the operational needs of today's water managers, short- and medium-term weather and climate forecasts can already meet their needs to a large extent. These forecasts have improved considerably in the past decade. Further improvement in short-term forecasting is seen as one of the most important technological breakthroughs that will improve our adaptive capacity.

- Short- to medium-term climate forecasts are, at present, not yet being used in water management in many parts of the world, partly for lack of capacity, but also because the potential has not yet been realised by water managers.

- Adaptation and coping measures are scale-dependent and may vary from individual households to local communities to catchments, as well as from national to international scales.

- As a rule, there is a limit to the resilience of water related systems and to the capacity of water resources managers to plan for, and operate within, any 'surprises' which may occur in anticipated changes in the climate.

- The protective value of natural systems for shielding communities and regions from climate related disasters has been chronically undervalued in decision-making. Measures that enhance both ecological and human resilience in vulnerable settings are, therefore, crucial for mitigating the growing risk of climate change and climate related disasters.

What particular challenges do lesser-developed countries face?

- The poor of the world are generally the most vulnerable to the impacts of climate variability and change on water, but they often have a low capacity to cope with such impacts.

- Even without climate change, most developing countries will be confronted with serious water problems by the middle of the 21st century.

- For water managers in developing countries, the impacts of changes in climate often appear minor when compared to some of the problems they are facing already. Population growth, urbanisation, land use changes and other drivers are just some of the causes of lack of access to water, over-abstraction, pollution of surface and groundwaters, as well as drying up of rivers and wetlands. Addressing strategies to adapt specifically to climate change may appear as an additional burden to water managers there, but may help reduce vulnerability to other changes.

- Few non-OECD countries can, therefore, presently afford actions to deal explicitly with impacts of climate change on water resources. At best, actions that address directly the more immediate water management problems are usually the only ones affordable to them. Planning for the future in lesser-developed countries may thus require financial and other assistance from developed countries.

- The fundamental differences in infrastructure, economic and human capacity, socio-political systems and environmental awareness between developed and developing countries (the 'North' and 'South') need to be borne in mind when considering Integrated Water Resources Management (IWRM) as an adaptation and coping strategy.

- As the largest contributor to anthropogenic climate change, the North indirectly places an additional burden on management of water resources in the South. That is seen as a further reason for financial assistance to the South, in line with the 'polluter pays' principle.

What are the information and knowledge gaps we are facing?

- To better understand the relationship between climate change and water resources knowledge needs to be enhanced, particularly on the processes of the hydrological cycle in relation to the atmosphere, land use and the biosphere.

- Expectations of water managers that output from General Circulation Models (GCMs) of climate change scenarios will be usable at the relatively detailed spatial and temporal scales at which they operate, will not yet be met in the next few decades. Major headway is, however, being made in refining regional scale climate models, which are coupled to GCMs.

- Flood and drought forecasting skills need to be improved over the entire range of time horizons of concern. This is where applied research and technology have a major role to play. Substantial developments in short- and medium- term weather forecasting, particularly quantitative precipitation forecasts, are needed for flood preparedness. Improving long-term predictability, based on climatic variability and sea surface temperature, emerges as an important tool for drought preparedness.

- Recognising that there is a need for better short- and long-range weather forecasts, the skill level already achieved in the current forecasts allows for some optimism in their application. Although examples of use, and potential use, and advances in institutional support are cause for optimism, the application of climate forecasting in water resources and agriculture is still too new to support the strong arguments that have been made about its value.

- Knowledge needs to be enhanced on 'preparedness of the water systems', e.g. regarding risk assessment, watershed management (such as controlling flood generation in source areas) and increasing water storage to serve both drought and flood protection.

- It is necessary to implement a global system, dedicated to addressing scientific issues, on assessing the 'intensification' of the hydrological cycle and for predicting and monitoring the effects of climate variability and change on water resources at the water manager's scale of operation.

- While our knowledge continues to increase about climate, water and vulnerability, we are still far from being able to reliably identify ‘hot spot’ areas of vulnerability.

- In order to make progress in identifying such areas, several tasks remain. These include clarifying the definition of ‘hot spot’ areas, specifying the thresholds of vulnerability, and developing a consistent framework for vulnerability assessment.

- The advantage of identifying ‘hot spot’ areas of potential and actual vulnerability is that society can devote its sparse scientific and policy resources to such limited areas. ‘Hot spot’ areas could serve as priority areas where society tries either to avert, or mitigate, climate-related risks.

What is the role of the private sector?

- The future of some private sector groups, which are associated with water issues, like (re) insurance, transportation or agriculture, could be particularly affected by climate change. Private sectors that traditionally have not concerned themselves specifically with water resources and its management should be made aware of the effects of climate change within the broader water-related sphere in the near future. The effects will not always be negative. New business opportunities are likely to emerge.

- Climate change alters precipitation, temperature and evaporation regimes. The impacts of climate change on crop production and food security could, therefore, be drastic in many areas of the world. Not only would water resources be affected significantly by shifts in agricultural production, but its potential impacts could affect international trade quite considerably. Climate change issues should, therefore, be considered in the next trade negotiations under the World Trade Organisation (WTO).

- Biotechnological advances in improving crop yields and tolerances to aridity and saline water, coupled with climate and weather forecasting, is likely to bring significant payoffs for a ‘no regrets’ strategy of adaptation in the field of agricultural water management.

- Opportunities exist for innovative approaches to financing the required coupling of investments in water infrastructure and environmental protection.

How do politics and institutions play a role?

- The political and institutional dimension is a most critical element in coping with climate variability and climate change from a water resources management perspective.

- The world's political leadership, with the support of international financing agencies, should invest in capacity building in the South to help them enhance their adaptation strategies to cope better with the potential impacts of enhanced climate variability and change.

- Concerted action, effectively co-ordinated across the various water use sectors, is required. A number of institutional and organisational issues have been identified to strengthen the preparedness systems. These include enhancing co-ordination, as well as drawing up clear divisions of competence, tasks and responsibilities among different agencies acting in watersheds (rather than acting only in administrative divisions) and assuring participation of stakeholders in decision-making.

- More and better quality water-related information should be made freely available to all who require it.

- More genuine co-operation must take place between institutions dealing with water, weather and climate, whether they be operational agencies or research groups.

What kind of dialogue is needed? Why? Amongst whom?

- Dialogue is required between the climate community and water managers. This will have to include dialogue on collection of suitable meteorological and hydrological data for predictions, on risk analysis and on dealing with uncertainty.

- As climate forecasts continue to become more accurate, the dialogue between meteorologists and water resources managers must keep pace with these advances in order to ensure knowledge is transferred between the groups.

- Furthermore, dialogue is needed on equity issues. Lesser-developed countries do not always have adequate financial and human resources to cope with hydrological extremes without some form of foreign and international assistance. Increase of effective assistance to the lesser-developed countries is seriously needed.

- The dialogue needs to be a multi-stakeholder platform. It should also involve the South more seriously in the debate on climate variability and change than it has in the past, as well as involving the various actors such as stakeholders, civil society, non-governmental organisations (NGOs) and governments. Different platforms for dialogue and discussion, which are tuned to the particular needs and interests of the regions and various actors, need to be provided.

TABLE OF CONTENTS

Chapter 1: Brief Overview of the Science on Water and Climate

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1.1 Introduction

Climate change is expected to have a major impact on water resources. In some regions increases in magnitude and frequency of extreme events are already being observed, and some experts are attributing this to a changing climate. Global increases in temperature will have profound effects on evaporation, which in turn affects atmospheric water storage and hence magnitudes, frequencies and intensities of rainfall events as well as the seasonal and geographical distribution of rainfall and its inter-annual variability. A high degree of uncertainty remains, particularly in the anticipated changes in rainfall characteristics with climate change. Water resources managers, in particular, face the challenge of incorporating the added uncertainty of the impacts of climate variability and climate change on hydrological responses into their decision-making process.

This chapter addresses water resource managers from a perspective of climate variability and potential climate change impacts. The focus is on relevant, real-world problems that they may face (in the present and future) in this respect. The phenomenon of climate change can be placed into context by first assessing the current state of climate (past to present) in order to understand the impact of possible future developments, Including gradual and abrupt changes on water resources.

It is not the objective of this chapter to duplicate the assessment reports of the Intergovernmental Panel on Climate Change, IPCC (IPCC, 2001). A brief summary of findings from the various IPCC reports on the theme of water and climate is provided in Appendix A. Rather, the chapter sets out to build upon the Panel's findings in a manner directed towards water resource managers. By selecting from the literature (particularly that of the IPCC), key concepts and facts on water and climate are introduced that will be addressed throughout this document.

This chapter is, in many respects, the point of departure of the Dialogue on Water and Climate, and aims at providing a brief overview summary on interrelationships between climate and water. The chapter commences with a brief discussion on climate, with a particular focus on uncertainties, and expected impacts on water resources. This is followed by a description on how the direct impacts of climate change and climate variability on water resources are expected to impact indirectly some other water related sectors such as agriculture, human health and ecosystems. Finally, current limitations to dealing with, and quantifying, these impacts are addressed.

1.2 Climatic Information

Climate research has a two-fold task (Hulme and Carter, 1999), *viz.*

- to increase the understanding of the climate system and
- to articulate and, here possible, quantify the uncertainties that remain.

These two tasks are addressed here with respect to water issues.

1.2.1 Current expectations of future climate in light of uncertainties

Understanding of changes in the past has often been constrained by a lack of observational evidence. Despite this restriction, it is likely that most of the observed global warming over the past 50 years is due to the increase in atmospheric greenhouse gas concentrations arising from anthropogenic emissions and land use changes. However, uncertainties concerning changes in the future arise from a combination of sources. Some sources of uncertainty are inherent, such as:

- future socio-economic, political and technological changes
- emissions of greenhouse gases in the 21st century and
- Variability within the climate system from year to year to year and its repercussions in water resource management.

Other sources of uncertainty are not inherent, and may be reduced. For example, confidence in the ability of global climate models to provide useful predictions of future climate has improved vastly in the past decade and the accuracy of the predictions has been demonstrated on a range of spatial and temporal scales. To cope with the various sources of uncertainty it is best to use a probabilistic approach, which takes science into the realm of risk assessment. The most recent assessment of the IPCC (IPCC, 2001) addresses uncertainty by considering a variety of different scenarios (Appendix A). Thus:

- a number of ‘storylines‘ of future world development are included
- many scenarios of greenhouse gas emissions for the 21st century have been developed (Figure 1.1)
- the amount of warming for an effective doubling of atmospheric greenhouse gas concentrations is permitted to vary from 1.4 to 5.8 °C and
- several different general circulation models of global climate represent regional climate changes.

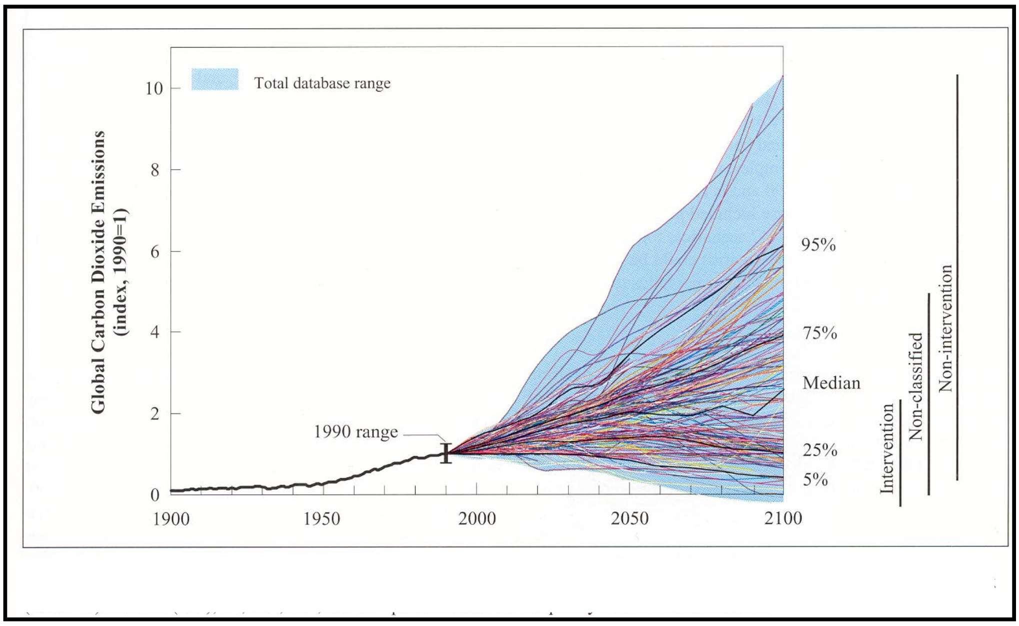


Figure 1.1 Global energy-related and industrial CO_2 emissions: Historical development and future scenarios, shown as an index where 1990=1 (Source: IPCC, 2001)

1.2.2 Anticipated global climate change and water resources

Since climate extremes which result in floods and droughts are of particular importance for water-related issues, and since these extremes may increase with global warming, it is imperative that water resources managers be aware of current forecasts of climate change, of their likelihood of occurrence and their likely effects on water resources. The confidence that may be attached to our understanding of changes in climatic extremes in the past and in the future is summarised in Table 1.1, which was drawn from the most recently published (2001) IPCC assessment and based on the approach to uncertainty outlined in Section 1.2.1.

Table 1.1 Summary of already observed changes, prospects for the future and likely impacts on water resources (Source: IPCC, 2001)

Climate change forecast	Climatic change already observed?	To occur in the 21st century?	Effects on water resources
• Higher maximum temperatures and more hot days over nearly all land areas	Likely	Very likely	Water resources reduced
• Higher minimum temperatures, fewer cold days and frost days, over near all land areas	Very likely	Very likely	Water resources reduced
• Diurnal temperature ranges reduced over most land areas	Very likely	Very likely	
• Increases of heat index over land areas	Likely over many areas	Very likely over most areas	Water resources reduced
• More intensive precipitation events	Likely over many northern hemisphere mid-to-high latitude areas	Very likely over many areas	More frequent and more severe floods
• Increased summer continental drying and associated risk of drought	Likely in a few areas	Likely over most mid-latitude continental interiors	More frequent and more severe droughts
• Increases in tropical cyclone peak wind intensities	Not observed in the few analyses available	Likely over some areas	More frequent and more severe storm-surge floods
• Increases in mean and peak precipitation intensities in tropical cyclone	Insufficient data	Likely over some areas	More frequent and more severe floods

1.2.3 Regional climate change

Although there is some disagreement as to what the globally averaged temperature increase is going to be, with modelled increases ranging from 1.4 to 5.8°C by the end of this century (IPCC, 2001), the different models agree that there will be large regional variabilities with the increase. For example, at high latitudes the temperature increase is several °C higher than at lower latitudes, in part due to the areal variation (i.e. reduction) in land ice and snow. Precipitation change is more spatially variable than that of temperature change. Although a general increase in precipitation is expected, some regions will see large increases, while others will see significant reductions.

There remains substantial additional uncertainty in the prediction of precipitation for two primary reasons:

- Precipitation is a secondary process in General Circulation Models (GCMs) and, as such, is poorly represented and
- Heavy precipitation systems frequently occur on scales that are considerably smaller than the typical grid scale of GCMs at 2-3°C latitude/longitude.

In order to obtain information at spatial scales smaller than a grid-box in a GCM, it is necessary to 'downscale'. There are two broad approaches to downscaling, neither of which is inherently superior to the other, and either of which may be appropriate in a given situation. These approaches are:

- *Statistical downscaling*, where an equation is obtained empirically to capture the relationship between small-scale phenomena and the large-scale behaviour of the model and
- *Dynamical downscaling*, where a high-resolution regional climate model (RCM) is embedded within a GCM.

Important to note is that 'System Earth' is a non-linear system. Changes in evaporation and precipitation are not linear with changes in temperature, in part because of fundamental physical principles involved, and in part because of the complexity of pathways and feedbacks affecting the link between temperature and other relevant climate variables at different scales. These non-linearities have far reaching consequences in water resources.

1.3 Water Resources

1.3.1 Why do water resources matter?

At the global scale, withdrawal and net consumption of water is expected to grow substantially during the next 50 years, owing to an increase in population, quality of life and food production. In addition, even if the trend of a decrease in net consumption continues in several of the most developed countries, the global increase of water use by 2025 is expected to be in the range of 25-50%, according to several development scenarios (Cosgrove and Rijsberman, 2000).

In essence, renewable water resources are finite, as they are limited by the flux of freshwater brought to, and withdrawn from, the continents by the processes of the hydrological cycle. Nevertheless, it is generally accepted that the *available* water resources are not equivalent to the sum of the annual river flows to the oceans. Floods compose a large proportion of the flows and when they occur as extreme events, they characterise a disaster rather than a beneficial resource. River flows are very unevenly distributed with time. Almost everywhere on Earth, river regimes show a strong seasonal variability. In areas such as the sub-tropics, or in Mediterranean-type climates, flows are often ephemeral and at times limited to a few weeks of the year. In cold regions, winter flows may be reduced significantly as a result of the retention of water in the form of snow and ice.

The spatial variability of surface flows is also striking. In the rural areas of developing countries the travel distance and time required for accessing and collecting the water can be long. Depending upon geological features, groundwater may be a convenient water supply option. However, frequently a groundwater source may be unusable, either because of the make-up of its natural chemical constituents (e.g. salt, arsenic) or because of anthropogenically induced pollution (e.g. nitrates). In addition, shallow aquifers may not withstand harsh dry seasons and as a consequence groundwater resources, as well as surface flows, may dry up.

In order to adapt to the variability of water resources in time and space, water supply and reticulation systems have been developed (e.g. dams, transfers of water by canals and pipes). However, the required investment in labour and/or capital implies the grouping of users around, or in, cities or market towns. Nevertheless, a sizeable proportion of the world's population still lives in scattered rural habitats and these people depend on the availability of water in its 'natural form' for satisfying their basic needs such as drinking, cooking, sanitation, cattle watering and agriculture. In differing climate regimes (e.g. sub-tropical, semi-arid, Mediterranean-type), such 'natural' availability of water is highly variable within a given year and between one year and the next. Any reduction in the amount of water resources or small changes in their distribution in time will lead to serious impacts for these communities if they are not supplied with potable water from external sources.

The concept of freshwater should not be reduced to that of a mineral flowing through channels, canals and pipes. Freshwater is an essential driver of terrestrial and aquatic ecosystems. Any state of equilibrium in the distribution of terrestrial ecosystems results from a balance between climatic conditions and the capacity for resilience of the systems to variations in those climatic conditions. Any change in the variability of climate, or any trend in any one of its components, may lead to latitudinal and altitudinal shifts in the distribution of terrestrial ecosystems (e.g. rainforests, savannas, steppes). In a given watershed (also termed catchment or basin), these changes might have tangible effects on the water budget and thus on the availability of water resources.

Freshwater ecosystems (such as ponds, lakes, wetlands and rivers channels) are essential components of the environment. They provide support for the existence of aquatic and terrestrial wildlife, environmental goods (e.g. water, foods) and services (such as flood attenuation, depletion of organic pollution). In many regions fish are a key element in the social and economic organisation of human communities and are the first source of proteins, and sometimes the only one, especially for the poor. Further issues on the importance of the environment in water resources, considering only present climatic conditions and not any further repercussions of enhanced warming or variability, are expanded upon in Box 1.1.

Unfortunately, water is also associated with specific diseases. There are several ways in which water is involved in transmission of disease:

- *Water-borne diseases* result from the contamination of water by human or animal faeces, or by urine infected by pathogenic viruses or bacteria, in which case the disease is transmitted directly when the water is drunk or used in the preparation of food.
- *Water-washed diseases* are those resulting from inadequate personal hygiene because of scarcity or inaccessibility of water. These include many water-borne diseases as well as typhus.
- *Water-based diseases* are those arising from parasites that use an intermediate host that lives in or near water (e.g. guinea worm).
- *Water-related diseases* are diseases borne by insect vectors, which have habitats in or near water (e.g. malaria).

- *Water-dispersed diseases* are infections whose agents proliferate in fresh water and enter the human body through the respiratory tract (e.g. Legionella).

With regard to water-related diseases, aquatic ecosystems are extremely sensitive, both positively and negatively, to any changes, including those related to climate change (e.g. changes in temperature of water, depth of water, velocity of water in streams).

Box 1.1 The importance of the environment in water resources

With a water crisis facing many countries, it seems an immense task just to manage water so that there is enough for domestic supply, agricultural and industrial uses. Thus, providing water to other users, such as the 'environment' is often given a low priority. Indeed, the situation is often presented as a conflict of competing demand, as though it was a matter of choice between water for people and water for wildlife. However, since the UNCED Conference in Rio in 1992, it has become increasingly recognised that the 'environment' means far more than just wildlife, although the need to conserve biodiversity is widely accepted. Functioning ecosystems perform vital functions such as flood reduction, groundwater recharge and low flow augmentation, and important products, such as fish, pastureland, reeds, medicines and timber (Acreman, 1998). Thus for the millions of people worldwide, particularly the rural poor who depend directly on natural resources or benefit from ecosystems, providing water for the environment and for people are one and the same (Acreman, 2001).

The Dublin Conference in 1992 (a preparatory meeting for UNCED) concluded that 'since water sustains all life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems'. For example, upstream ecosystems need to be conserved if their vital role in regulating the hydrological cycle is to be maintained. Well-managed headwater grasslands and forests reduce runoff during wet periods, increase infiltration to the soil and aquifers and reduce soil erosion. Downstream ecosystems provide valuable resources, such as fish nurseries, floodplain forests or pasture, but these must be provided with freshwater and seen as a legitimate water user. At the UNCED Conference itself, it was agreed that '*in developing and using water resources priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems*' (Agenda 21, Chapter 18, 18.8). Thus whilst people need access to water directly to drink, irrigate crops or supply industry, providing water to the environment means using water indirectly for people. The declaration from the Second World Water Forum in The Hague in 2000 highlighted the need to ensure the integrity of ecosystems through sustainable water resources management. South Africa is one of the countries which have taken a lead in implementing this concept. Principle 9 of the new (1998) National Water Act of South Africa states that 'the quantity, quality and reliability of water required to maintain the ecological functions on which humans depend shall be reserved so that the human use of water does not individually or cumulatively compromise the long term sustainability of aquatic and associated ecosystems'. The 1996-2001 Fifth International Hydrology Programme of UNESCO included an Ecohydrology project which includes ecosystem management to improve water quality, particularly in the form of buffer strips to ameliorate the impacts of agricultural pollution. The World Commission on Dams (2000) recommended the release of environmental flows from dams to support downstream ecosystems and their dependent livelihoods.

Although figures show that at the global level the increase of water demands and uses appears as being the determinant driver in what can be considered as a looming crisis, it must be pointed out that the relationship of humans with water is largely defined at the local level, with water being considered either as a resource or as an ecosystem. Global and even national indicators hide the obvious fact that for all beings, scarce water means survival and no water at all means death within a few days. In many stressed environments, the resource component in the demand/supply balance may, indeed, become the key issue if the resource is modified in total amount or in its temporal or spatial distribution by, for example, changes to mean climates and climatic variability.

1.3.2 What do we know from past experiences of climate variability and change?

Observation of historical data series has demonstrated that the sequencing of wet and dry years is not distributed evenly, but rather that extended dry and wet periods can occur in some regions. This is illustrated in Figure 1.2 for annual rainfall averaged over South Africa for the period 1922-1999. The drought experienced in West Africa during the 1970s and the 1980s is another illustrative example in this regard (Table 1.2).

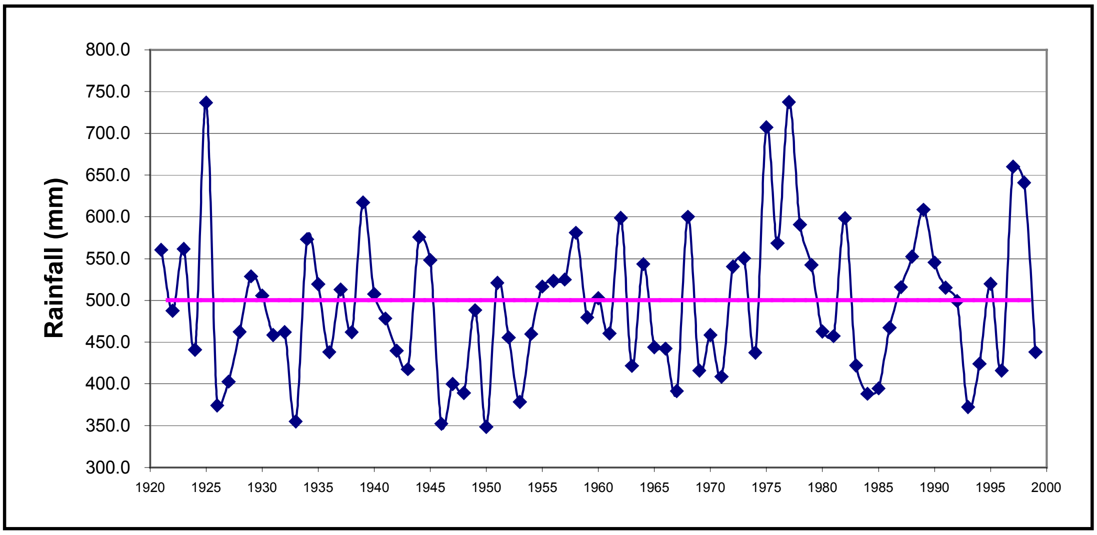


Figure 1.2 Annual averages of rainfall over South Africa (1922-1999) illustrating the frequent persistence of a series of wet or dry years (Source: South African Weather Service, 2000)

Table 1.2 Decreases of precipitation for countries in West and Central Africa and decreases of river flows in the same region. The averages of the period 1970-1989 are compared with those from the period 1950-1969 (Source: Servat et al., 1998)

Country	Reduction in Precipitation (%)
Cameroon	16
Togo	16
Central African Rep.	17
Benin	19
Ghana	19
Nigeria	19
Guinea	20
Chad	20
Ivory Coast	21
Burkina Faso	22
Guinea Bissau	22
Mali	23
Senegal	25

River	Gauging Station	Reduction of Annual Flow (%)
Comoe	Aniassue	50
Chari	Ndajmena	51
Logone	Lai	39
Niger	Malanville	43
Niger	Niamey	34
Bani	Douna	70
Oueme	Sagon	42
Sassandra	Semien	36
Senegal	Bakel	50
Bakoye	Ouali	66
Black Volta	Dapola	41
Black Volta	Boromo	46
Oubangui	Bangui	30

Secondly, climate variability is amplified through the hydrological cycle. For example, Table 1.2 shows for West and Central Africa that an approximately 20% decrease of precipitation during the two decades of the 1970s and 1980s translated into an approximately 50% reduction in annual flows. In others words, what can be considered as a small change in the total, or in temporal, patterns of precipitation may well have considerably larger tangible effects on the water resources.

Thirdly, past and current experiences also illustrate positive anomalies in runoff. For example, the succession of high flows of the Volga River (which contributes 85% of the incoming water to the Caspian Sea) has triggered an elevation of the sea level of nearly 3 metres since the 1970s, in spite of the uptake of water in the river and its tributaries (Shiklomanov et al., 2000). Such high levels of the sea have not been observed since the 1930s. Thus, since peoples' memories are relatively short, infrastructure and property have been established and subsequently lost in the now flooded area.

Fourthly, experience has shown that the hydrological cycle has certain resilience, i.e. it is able to accommodate only a certain level of external forcing, such as a reduction in precipitation. If, however, the forcing is too strong, or is maintained for too long, river flows may drop suddenly and sharply, with the associated consequences for the different users of water (the ecosystems and Man). For example, Figure 1.3 illustrates this concept, as a prolonged decrease in precipitation results in a sharp reduction in river flow for the Bani River, a major tributary to the Niger River in Mali.

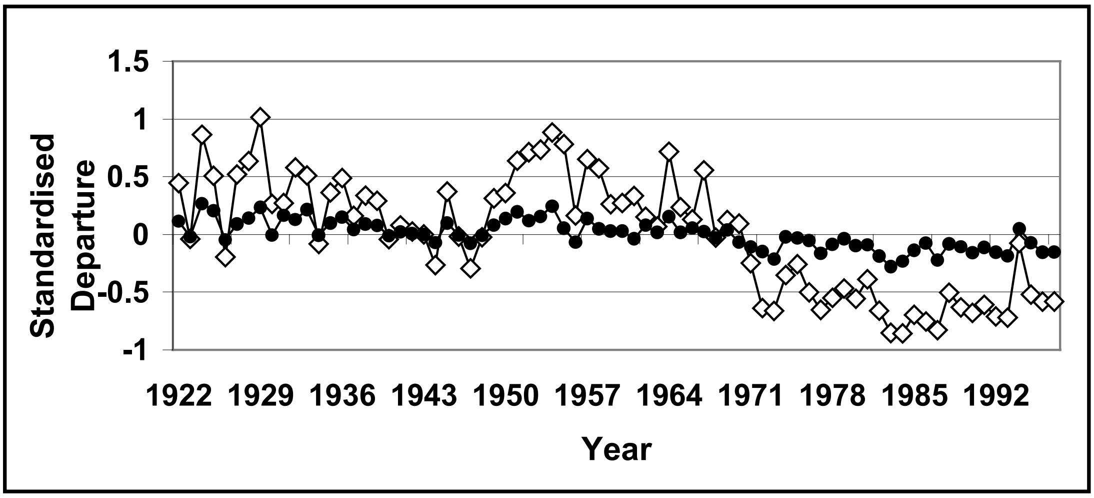


Figure 1.3 Bani River at Douna (Mali). Compared evolution of precipitation (black circles) and river flow (open diamonds) for the period 1922 to 1997. Units: Standardised departure from the inter-annual mean (Source: Mahé et al., 2000)

In addition and fifthly, water resources are extremely sensitive to complex feedback mechanisms due to the non-linearity of most hydrological processes. Sediment flows in rivers provide a vivid illustration of these concepts, as shown in Figure 1.4. Sediments are highly mobilised during major floods and sediment discharge increases exponentially with the intensity of the floods. If the river is dammed, these sediments are trapped in the reservoirs and subsequently they reduce the storage capacity.

Particularly in semi-arid areas, the operational lifetime of a reservoir depends on the siltation rate. Thus, water schemes in semi-arid areas are economically viable only for a given sedimentation rate, corresponding to the conditions prevailing at the time of their design. If more frequent floods were to be associated with climate change, and these floods were characterised further by greater magnitudes (or even by similar magnitude) than in the past, any sediment discharge model will show that a doubling of the sedimentation rate in the reservoirs can easily be achieved. This would mean that the life expectancy of the scheme would be half of what had initially been planned.

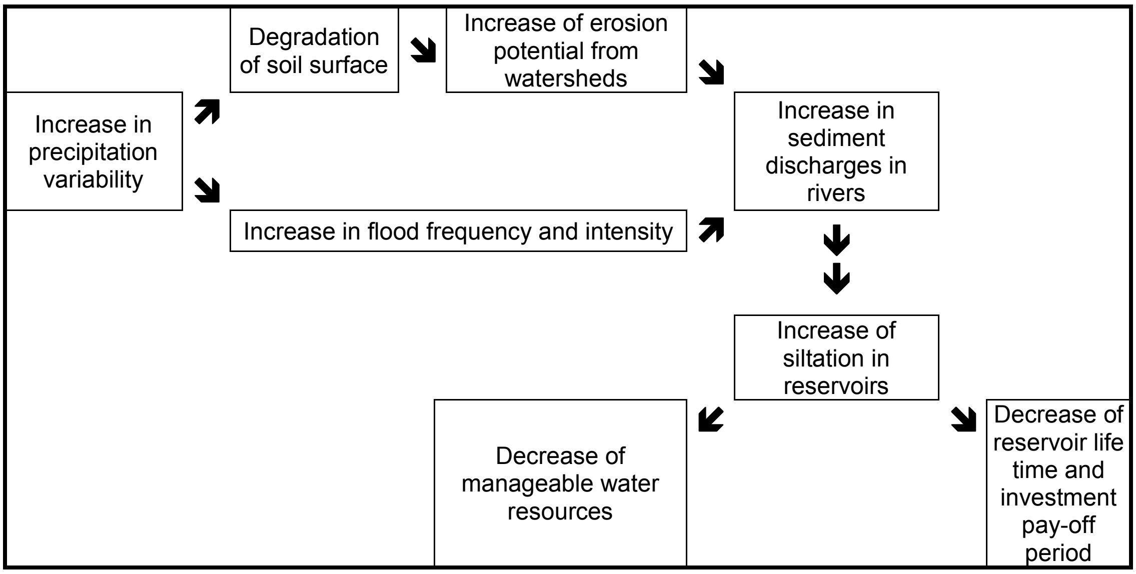


Figure 1.4 Small changes in precipitation patterns may lead to very significant increases in sediment flows, with corresponding impacts on the management and on the financial conditions of water resources planning (Figure contributed by J.M. Fritsch, WMO)

1.3.3 What do we expect for the future?

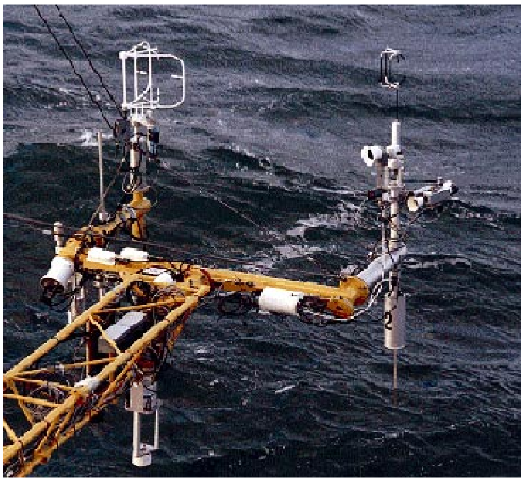
A significant proportion of the solar energy received by the Earth is utilised in driving the hydrological cycle, i.e. for evaporating vast quantities of water of which 40 000 km^3 are moved and precipitated over the continents every year. The increase of greenhouse gas concentrations in the atmosphere will lead to an increase of the available energy on the surface of the Earth and thus, according to the basics of thermodynamics, an 'intensification' of the hydrological cycle will occur. At the global scale, all GCM simulations have verified this.

The oceans play a major role in climate, as they are able to store and to release sizeable proportions of the incoming energy. Thus, experience and the most advanced knowledge on climate processes are consistent in the prediction that the expected intensification of the hydrological cycle will not be experienced merely as a smooth linear trend, but rather in the form of oscillations of the variability of climate. The oscillations may be more frequent than in the past and the amplitude of the variability may also increase over some areas (Kabat et al., 2003).

Most of the geochemical and biochemical characteristics of water are acquired during its travel from the clouds to the rivers, through the biosphere, the soils and the geological layers. Changes in the amounts, or patterns, of precipitation will alter the route and the residence time of water within the watershed and change its quality, in such ways that the resource might be lacking, not because of the quantity, but because its newly acquired quality may have render it unsuitable for the required use. For example, there are real risks that an increase of the concentration of dissolved salts may occur as a result of an increase of evaporation under higher temperatures. The risk of increased salinity might also be associated with excesses of water. Under such conditions the water tables, which were previously kept at a given distance under the surface, may rise and reach horizons of soils, which may then be salinised or contain agrochemicals or industrial wastes. The water from these shallow aquifers may eventually be drained into the river network and reduce the quality of the water further downstream.

1.3.4 How reliable is our information?

To be able to assess any changes in river flows, aquifer levels or freshwater ecosystems and to predict their behaviour in the future, two conditions need to be met, *viz.*



- we need to have ready access to sufficient and reliable local data and information to address issues of changes in hydrological responses for a given basin or region and
- we need to have the capacity to model hydrological processes realistically.

Contrary to climate information, which is generally collected for scientific purposes, most information on hydrology and water resources is collected for management purposes. The consequence is an institutional fragmentation of the collection process country by country, and even within a single country, where different water use sectors (e.g. energy, navigation, agriculture, domestic supply) may operate their own specific networks and use different procedures for the collection, storage and retrieval of data. Moreover, while there is a long tradition for exchanging, or freely disseminating, atmospheric information at the global level, the free availability of water-related data remains, in many cases, a sensitive issue as it applies to an economic resource. Several initiatives, including Resolution 25 (Cg-XIII) adopted by the World Meteorological Organisation, WMO, are advocating sharing of hydrology-related data. However, there is still a long way to go to match the effectiveness of the World Weather Watch of the WMO.

The retrogression of many national meteorological and hydrological services, and consequently of the maintenance and operation of their networks and field stations, are another very serious cause for concern. The governing concept seems to be that any water crisis is, in the first instance, a management crisis or a supply side issue, rather than a resources crisis. This may be true in global terms. However, political interest in, and financial support for, the monitoring of weather and water resources has been shrinking markedly in most countries. The effects of such a rationale are definitely jeopardising our capacity for addressing some major issues of water resources under conditions of current climate variability and of possible future change, as well as for forecasting and monitoring accurately water-related disasters and for planning the equitable share of the benefits of water in large transboundary river basins.

The retrogression of data collection varies from case to case. In some cases the number of stations has declined, while in others the number of stations may have been maintained, but the quality of the data (i.e. its accuracy, or continuity over time) might have regressed to the extent they become unusable. Figure 1.5 shows an example of the latter case for a country of Sub-Saharan Africa. Although the number of rainfall stations has remained steady, the frequency of observation gaps has increased dramatically, thus rendering unusable the time series from a number of rainfall stations. Figure 1.6 illustrates that the decline in monitoring activities is not necessarily limited to the developing countries.

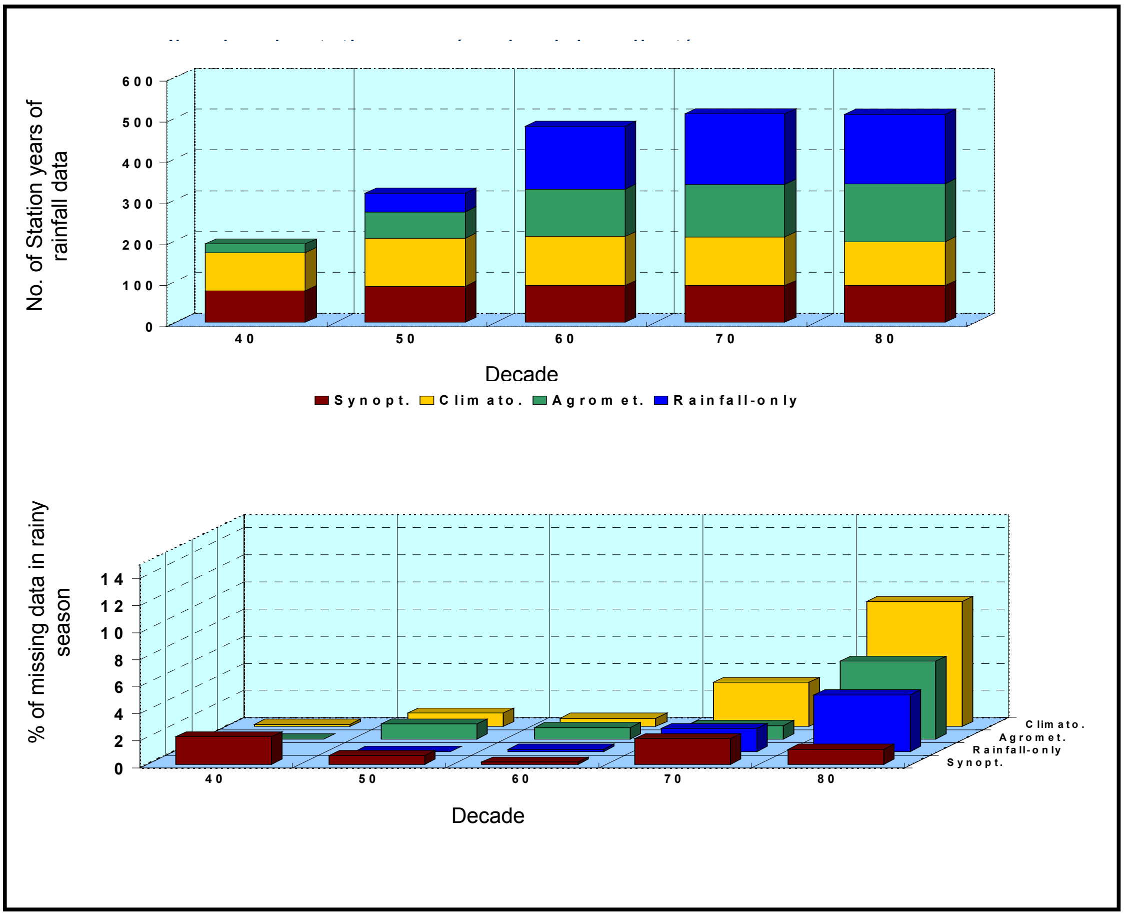


Figure 1.5 Example of the retrogression of the quality of hydrometeorological data in a country of Sub-Saharan Africa (Source: Worldbank, 1991)

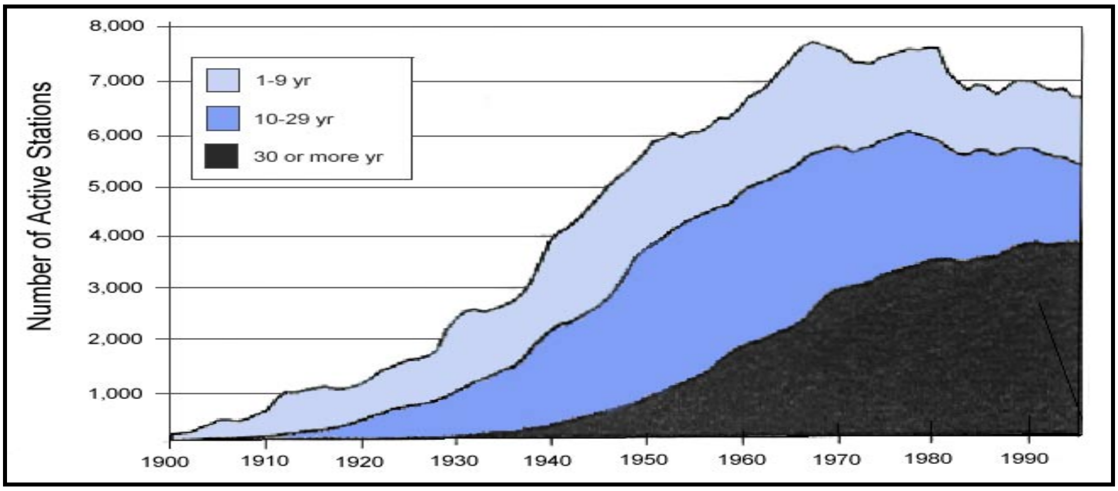


Figure 1.6 Number of active discharge monitoring stations in the USA from 1900 to 1996 (Figure contributed by J.M. Fritch, WMO)

Modelling of hydrological processes, both for planning and prediction, is dependent upon good quality data. Currently, relevant information on hydrological processes may be obtained from two particular types of models:

- *Hydrological models* simulate the transformation of precipitation into runoff. Spatially, models can be structured to operate at global or regional or basin or small catchment resolutions while temporally, scales can range from annual to monthly to daily and hourly, depending on their application. While commonly used for long-term planning purposes, rainfall:runoff models are not always yet a routinely applied component in a real-time flood prediction system. Under conditions of extreme events, physically based hydrological models do not necessarily generate output as realistically and robustly as simpler conceptual ones do.
- *Hydraulic models* provide details of flow rates and stage heights, and hence the propagation of flood waves, for different locations along the river channel and at different times. These models are highly developed for many large river systems, and they have served to produce flood level projections for many years. Since such models mimic the propagation of an already existing flood wave in a channel, the lead time that downstream populations have in order to prepare for a predicted flood stage height depends upon the size of the catchment and the distance of the population centre from the flood wave. While for the river Rhine at Cologne this lead-time is slightly longer than two days, for smaller catchments the lead times may be too short in duration to adequately prepare flood warnings or evacuate affected populations. In such cases, hydraulic models are of little use for real-time flood forecasting.

The challenges for the future lie in the improvement of representations of hydrological and hydraulic processes in these models, for they remain simplifications of complex dynamic interactions and in the coupling of these modelling systems to allow for improved early warning lead times in accordance with increased reliability of weather forecasts. Another challenge is modelling extreme events under future climatic conditions. Recent advances in forecast skills augur well for improvements in preparedness systems for water-related disasters. In particular, improved understanding of the role of the land surface in coupled land-atmosphere-ocean models and of hydrological responses of very large river basins offers new challenges and opportunities (Kabat et. al., 2003).

As an example, Wood et al. (2002) applied hydrological forecasting techniques during the summer drought of 2000 in the eastern and central USA. Climate forecasts of precipitation and temperature for six-month lead times, updated monthly, were downscaled, and spatial model output and streamflow were generated for each month of the six-month forecast horizon. More recently, this streamflow forecasting strategy has been implemented over the Columbia River basin to produce six month lead time forecasts, allowing the probability of reservoir refill to be assessed at regular intervals.

1.3.5 How do we prepare for the future?

Several steps, which are elaborated on below, need to be taken in order to prepare for the future:

- More and better quality water-related information should be made freely available.
- Genuine co-operation must take place between institutions responsible for water, weather and climate, whether they be departments of state, operational agencies or research groups.
- Further enhancement of knowledge is required on the processes of the hydrological cycle, and their model representations, particularly in relation to the atmosphere and the biosphere.
- It is necessary to implement a global system, one more dedicated to addressing scientific issues, for assessing the predicted 'intensification of the hydrological cycle' and for predicting and monitoring the effects on water resources at regional and local catchment scales.

More and better quality water-related information should be made freely available. In many countries it will be necessary to rehabilitate the water-related data collection systems. Depending upon the respective country conditions, this may require strengthening the technical capacity of the National Hydrological Services (NHS). The NHS are generally in charge of maintaining, rehabilitating and expanding the field networks, as well as improving the processing, storage and distribution of the data and information. Providing the NHS with an adequate budget to cover their operational costs for the next decade is, therefore, a top priority. This would require combined efforts from the individual nations and from the international community.

Once the data collection has been re-established, international standards should be applied to the measurements, the data validation, its encoding and distribution. The prerequisite for external input in the water-related data collection in any country should be that all data will be available easily and freely, at least for the science community, through state-of-the-art communication media (Internet).

Present climate is characterised by natural variability of climatic events such as droughts, heavy precipitation and gales. The risk to the human population is governed by the occurrence of extremes in these events and related hazards, such as flooding. Changes in extreme events may have a profound impact on humans. In many areas of the world, little is known about even the natural occurrence of extreme events, although such information is often buried in local data sets. Without this baseline information, information about future changes in climate extremes loses much of its significance.

An important part of the programme to raise awareness of the link between climate and water should be 'data mining', or 'data rescue', in developing countries. This should be followed by an investigation of the statistics of extremes in the baseline periods defined by the availability of the local sources. Baseline studies are particularly relevant in those regions, which are identified as 'hot spots'. Once these statistics are known, the questions as to the vulnerability of societies to natural hazards, and how the effects of climate change could introduce changes in this vulnerability, can be answered.

Genuine, actual co-operation must occur between institutions dealing with water, weather and climate, whether they are departments of state, operational agencies or research groups. As far as possible, the aim is to generalise the forecasting of the status of water resources at all time scales, from days to months for operational and tactical management and from years to decades for taking wise strategic decisions. It has to be noted, that in many countries, the relationships between practitioners and scientists dealing with the atmosphere and the water sector are virtually non-existent.

Dialogue and communications links need to be established, as do procedures for receiving and using weather and climate information and forecasts in water management.

Knowledge must be enhanced on processes of the hydrological cycle in relation to the atmosphere and the biosphere. It has been noted in the IPCC reports that there is less uncertainty in temperature predictions than in precipitation predictions and, in turn, for precipitation compared with river flows and aquifer levels. This is due partially to a lack of reliable water-related data, but also to the state of knowledge, in particular of the process representations in the hydrological models used for integrating, in prediction mode, all those feedback effects with the land surface and the biosphere. GEWEX-BAHC and similar programmes should be strengthened and the selection of their experimental observation sites should be made taking into account real water management issues in the context of climate variability and change (Kabat et. al., 2003).

Besides the needs for improving the operation of national and regional measurement networks for water management purposes, it appears necessary to also implement a global system, more dedicated to addressing scientific issues, to assessing the anticipated 'intensification' of the hydrological cycle and for predicting and monitoring the effects on water resources. This may not require the implementation of a specific network of ground stations, but rather include existing key stations into the system, and to then update and standardise equipment as well as operating procedures, including a near real-time distribution of streamflow data, as it is the case for the global climate and weather research programmes. The World Hydrological Observation System (WHYCOS) of the World Meteorological Organisation and the Global Terrestrial Network – Hydrology (GTN-H) of the GCOS Programme would provide, among others, convenient frameworks for implementing such an initiative.

1.4 Impacts of Climate Change on Water-Related Extremes: Background

Natural disasters associated with extreme events occur regularly throughout the world (Figure 1.7). This section focuses on water-related extreme events, primarily due to their societal relevance. There has been increased attention on extreme weather and climate events over the past few years, as a result largely of exponentially increasing losses which have been associated with them. These losses are as a result largely mainly to an increase in the vulnerability of society as a whole to extreme events (Kunkel et al., 1999). In many cases this increased vulnerability has not been matched by an appropriate increase in adaptive capacity. Increased population concentrations in flood prone areas, as well as land use and river channel changes are the main contributors to this enhanced vulnerability.

It is more difficult to actually quantify the role of climate change in the occurrence of extreme events. Lack of long-term climate data suitable for analysis of extremes is the biggest obstacle to quantifying whether extreme events have changed over the 20th century, either world-wide or on a more regional basis (Easterling et al., 1999). However, recent changes in climate variability seem to have adversely affected flood and drought hazards in several regions and this tendency is likely to continue.

Such adverse effects have already been observed in water-related extremes linked to possibly changing climatic variability. The frequency and intensity of El Niño–Southern Oscillation (ENSO) events have been unusual since the mid-1970s, when compared with those of the previous 100 years. Warm phase ENSO episodes have become more frequent, persistent and intense. During such El Niño phases, extreme water-related events occur more frequently, through intensive precipitation (and floods) in some locations and precipitation deficits and droughts in other regions.

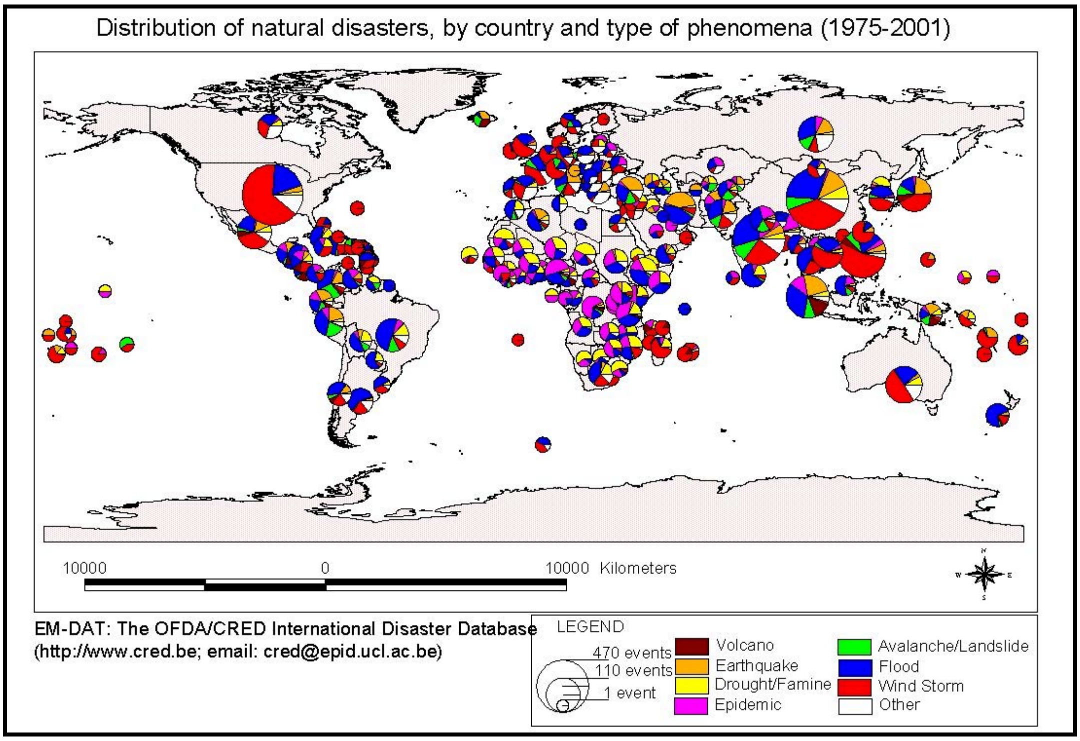


Figure 1.7 Distribution of natural disasters, by country and type of phenomena (Source: CRED, 2002)

In addressing water-related extremes, and the impacts climate change could have on them, the focus will be on riverine floods (as distinct from coastal flooding, which is beyond the scope of this document) and on droughts. In both cases attempts are made to answer the following:

- Why do they matter?
- What do we know about them from the past?
- What do we expect of them in the future?
- What are our information needs? and
- How do we prepare for the future?

1.5 Floods

1.5.1 Why do floods matter?

For millennia, people have settled in floodplains in order to till fertile soils, use the flat terrain for settlements, have easy and safe access to water and to use the river for transport. Riverine floods are natural phenomena: they have always occurred and people have tried to benefit from them to whatever extent possible. However, in recent decades humans have become more exposed to the risk of floods.

Different pressures have combined to increase population densities in flood-prone areas, including shortage of land, which has caused encroachment into floodplains. In particular, the mushrooming of informal settlements in endangered zones and around mega-cities in developing countries has occurred as people migrate towards economically developed city centres. The hope of overcoming poverty drives poor people to migrate, frequently into places vulnerable to flooding and where effective flood protection is not assured. In fact, in many countries such places are left uninhabited on purpose, exactly because they are flood-prone.

As a consequence, riverine floods have affected large numbers of people in recent years – on average more than 100 million people per year. From 1990 to 1996 there were 6 major floods throughout the world in which the number of fatalities exceeded 1000 while there were 22 floods with losses exceeding $US 1 billion each. According to the Red Cross, floods in the period from 1971 to 1995 affected more than 1.5 billion people worldwide. This total includes 318 000 killed and over 81 million homeless (IFRC,997).

In addition, the impact of floods has had increasingly detrimental and disruptive effects on, *inter alia*,

- human health (*e.g.* the increased spreading of diseases such as diarrhoea or leptospirosis in flooded areas)
- settlements and infrastructure
- coastal areas
- financial services (including insurance and reinsurance)
- transport
- water supply
- agriculture and
- ecosystems.

By way of example the Mozambique floods of 2000 and 2001, which were devastating not only in terms of direct loss of life, but also in terms of human health, are used to illustrate the impacts of excessive rainfall (Box 1.2).

The negative aspects of floods have been stressed thus far in this section. This does not imply, however, that all floods are bad. Floods are the life blood of many ecosystems, including the floodplains and deltas. When flooded periodically, these wetland ecosystems supply important products (e.g. arable land, fisheries, livestock grazing), functions (e.g. groundwater recharge, nutrient cycling) and attributes (e.g. biodiversity), which have contributed to the economic, social and environmental security of rural communities worldwide for many centuries. Floods are also very important for fish migration and sediment transport. Furthermore, it is becoming more widely recognised that reduction in the frequency and magnitude of flooding caused by dams alters the conditions to which ecosystems have adapted and may degrade the natural services that provide benefits to people. In response, the release of managed floods was recommended by the World Commission on Dams (2000) and agreed as best practice as part of dam management by the World Bank (Acreman, 2002).

Box 1.2 The Mozambique floods of 2000 and 2001

In the beginning of February 2000, torrential late summer rains of return periods up to 200 years in places fell over parts of Southeastern Africa (Smithers et al., 2001). The combination of two cyclonic systems in rapid succession and high levels of antecedent soil moisture from a wet early summer resulted in extraordinary flooding. Mozambique was affected most severely, but parts of other countries in the region such as South Africa, Zambia, Zimbabwe, Botswana, Swaziland and Madagascar also suffered. Mozambique experienced the biggest flood known in the history of that country. A year later, in February 2001, Mozambique once again faced a flood disaster, while still suffering from the effects of previous year's devastating floods.

The damage in 2000 was catastrophic: whole villages were covered by water, entire crops destroyed, arable land rendered unusable for the next three years, people seeking refuge on roofs of houses and tree tops. Whole sections of main roads were also washed away, isolating many towns and villages, including the capital city, Maputo. The disaster left 700 people dead and half a million homeless. According to the UN World Food Programme, Mozambique lost at least a third of the staple maize crop and 80% of its cattle. A quarter of the country's commercial agriculture was damaged.

The 2001 flood disaster carried away thousands of homes and inundated vast areas of farmland. At least 400 000 people were affected, with more than 40 people killed and 77 000 rendered homeless.

During and after the catastrophic flood of 2000, it became clear that as well as food and medicine, availability of clean water was a critical issue. The threat of diseases, malnutrition and lack of clean water after the flood caused a higher death toll than that directly by the floodwaters. The implication was that, besides the direct assistance during the inundation, it was most important to start with the post-flood aid as early as possible. In this case, international aid started late (with the exception of that from the Republic of South Africa), as the international press coverage on the flood was initially scanty. The heavy rainfall began on 3 February of 2000, inundations already started on 9 February, but there were no major press reports in, for example, the USA until 1 March.

An expert workshop organised by the Mozambique government, the Preparatory Secretariat of the 3rd World Water Forum and the IAHR listed the required actions for an improved flood mitigation of the southern African catchments. This list includes the pledge for an improved hydrological observation network, well balanced non-structural and structural measures, and an integrated approach towards flood management, including the involvement of the local people and the establishment of regional river boards for the international river basins in that region.

1.5.2 What do we know from the past about floods?

Berz (2001) examined inter-decadal variability of major flood disasters, where flood disasters are understood to be those where the ability of the region to help itself is distinctly overtaxed, and thereby making international or interregional assistance necessary. Based on the data for the period 1950 to 1998, Berz (2001) contended that the number of major flood disasters had grown considerably world-wide in the past decades (six cases in the 1950s, seven in the 1960s, eight in the 1970s, 18 in the 1980s, and 26 in the 1990s). The number of major flood disasters in the decade of the 1990s was higher than in the three decades from 1950 to 1979.

In the 1990s, there were over two dozen flood disasters worldwide in each of which either the material losses exceeded $US 1 billion, or the number of fatalities was higher than 1000, or both. In the most disastrous storm surge flood in Bangladesh, during two days in April 1991, 140 000 people lost their lives. The highest material losses, of the order of $US 30 and 26.5 billion respectively, were recorded in China in the 1996 and 1998 floods.

As far as the geographic distribution of the most disastrous floods is concerned, the majority of recent large floods have occurred in countries of Asia. However, few countries of the world are free of flood danger, as demonstrated by the unprecedented floods in 2002 in Central Europe. Even countries located in dry areas, such as Yemen, Egypt and Tunisia have not been flood-safe. It is counter-intuitive, but true, that in dry areas more people die of floods than from lack of water, as the dryness is a normal state to which humans have adapted, while floods strike unprepared populations suddenly.

Although water-related extremes strike developed and less developed countries alike, their consequences are largely different. In developed countries, the material flood losses continue to grow, while the number of fatalities decreases. Advanced flood preparedness systems can save lives - the fatality toll in developed countries is far less than in the less developed ones. For catastrophic floods in developing countries, material losses per single fatality can be as low as $US 21 000, while in developed countries they can be as high as $US 400 million.

Precipitation is a critical component in causing floods, and the location, form, amount, and intensity of precipitation appears to be changing. During the 20th century precipitation has increased by between 0.5 and 1.0% per decade in many areas over much of the mid- and high latitudes of the Northern Hemisphere. In regions where the total precipitation has increased, there have been even more pronounced increases in heavy and extreme precipitation events. Moreover, increases in intense precipitation have been documented even in those regions where the total precipitation has decreased or remained constant. However, one has to be careful with generalisations: there are some regions which have shown decreases in precipitation and precipitation intensity. Box 1.3 describes the 1997 European floods in the Oder River, where extreme levels of precipitation were observed.

Changes in runoff are generally more difficult to detect than changes in precipitation. Nonetheless, an increasing number of large floods has been observed, as well as increasing flood damages in several areas such as in the USA. Moreover, a change in the seasonality of floods has been detected. This is due, in part, to earlier flow maxima following milder winters, and to a more persistent El Niño state. However, it would be a gross over-simplification to state that floods have exhibited growing trends everywhere. Signals in some river flow data, which have been ascribed to global warming, have not been confirmed by research elsewhere. The time series of flood data reflect complex responses due to other, non-climatic factors such as changes in catchment land use or manipulation of water within the channel (e.g. dams, abstractions, canalisation), and behaviour of such time series is not necessarily in tune with expectations from global climate-related prognoses alone.

The costs of extreme weather events have exhibited a rapid upward trend in recent decades and yearly economic losses from large events have increased ten-fold between the 1950s and 1990s. Part of the observed upward trend in weather disaster losses is linked to socio-economic factors, such as increases in population and wealth as well as settlements expanding in vulnerable areas. However, these factors alone cannot explain the observed growth in economic losses. A part of losses can be linked to climatic factors, such as the observed changes in precipitation.

An example of research which links rates of change in flood characteristics and socio-economic indicators is that by Pielke and Downton (2000) in the USA for the time period from 1932 to 1997. They found that the total annual flood damage, adjusted for inflation, has grown at an average rate of 2.92% per year. That is a stronger growth than that of population (+1.26%) and tangible wealth per capita (in inflation-adjusted dollars +1.85%).

Box 1.3 The Odra/Oder flood of 1997 (Source: Kundzewicz et al., 1999)

One of the most devastating recent floods in Europe was the July 1997 flood on the Odra (Oder in German), the international river whose drainage basin is shared by the Czech Republic, the Republic of Poland and the Federal Republic of Germany. The flood, caused by a sequence of intensive and long-lasting precipitation, reached disastrous levels in terms of both river stage/discharge and consequences.

From a hydrological perspective, the Odra flood was a very rare event with return periods in some river cross-sections of the order of several hundred years. In large parts of the region in which the flood originated, the July values of precipitation were more than 300 % of the monthly mean, in the mountainous areas even more than 400 % (Malitz, 1999). In Racibórz-Miedonia, on the Polish stretch of the Upper Odra, water reached the culmination stage at over two metres higher than the maximum observed to date and the corresponding flow was about twice as high as the historical record. When moving downstream, the flood became less intense. However, even in several downstream river reaches, the peak discharge exceeded return periods of 100 years. The summer of 1997 flood on the Oder lasted several weeks. Even the exceedance of the historical absolute maximum water levels persisted for up to 16 days.

The number of flood fatalities in Czech Republic and Poland reached 114 (Grünewald et al., 1998). In all three riparian countries the economic losses were immense. However, there is a very high uncertainty in quantifying the economic losses. The values range between $US 0.55 and 2.2 billion in the Czech Republic, between $US 2.5 and 4.0 billion in Poland and between $US 0.3 and 0.7 billion in Germany. Since for several years before 1997 only minor floods had occurred in Poland, the awareness and preparedness of the nation was largely inadequate (Kundzewicz et al., 1999). The structural flood defences for several larger towns on the Odra and its tributaries and for vast areas of agricultural land, proved to be dramatically inadequate for such a rare flood. Flood defences, designed for smaller, more common floods, failed when exposed to a much higher pressure.

Organisation also turned out to be a weak point, especially at the commencement of the flood. Legislation was inadequate, e.g. financial aspects and the division of responsibilities and competences. As a result, regional and local authorities were uncertain as to their share in the decision-making, and this had financial implications.

The upsides were accelerated awareness raising and a generation of national solidarity. Combating the flood at the Polish reach of the Lower Odra was a real success story. The impression of disorder gradually decreased. Indeed, if a surprise of such an extraordinary magnitude occurs, it was shown that time was needed to adapt.

An analysis of the course of the flood and related damages clearly shows the necessity for a series of flood protection and management strategies in all three riparian countries (Bronstert et al., 2000). These include the creation of increased water retention potential within the river network system, measures to reduce and delay flood runoff generation and operational needs such as an improved and transboundary flood forecasting system. Research needs comprise an inter-disciplinary perspective of flooding, including human factors. Finally, it should be emphasised that a change of peoples' view towards a culture that lives with risks needs political initiatives and related, long-term conceptions on what risk implies.

1.5.3 What do we expect for the future?

There are a number of possible reasons why, in a warmer future climate, the frequency of floods may increase in any particular region. These include (IPCC, 2001):

- more frequent wet spells in middle and high latitude winters
- more intense mid-latitude storms
- a more El Niño-like, i.e. warm phase, mean state of the ENSO
- an increased frequency of extreme precipitation events
- increased magnitudes of precipitation events of high intensity and
- land use change as well as surface degradation (e.g. deforestation, urbanisation).

1.5.4 What are our information needs on flow data?

Broad spatial coverage of river flow data exist in general. However, the spatial coverage of gauging stations is far from being uniform. Furthermore, there is a dearth of time series data from catchments which remain in pristine condition and in which human impacts have been truly minimal. Long time series of records of river flow and other hydrological data are urgently needed (including proxy data).

Progress is needed in the development of a toolbox for trend detection - allowing one to disentangle climatic and other drivers in flood data. This is, in general, a very difficult task, as there are problems with data and with methodology.

1.5.5 How do we prepare for the future?

Flood protection measures can be structural or non-structural. Structural measures include:

- dams
- flood control reservoirs, i.e. constructing reservoirs where the excess flood waters can be stored, and then released as a controlled flow to help alleviate the flood problem by attenuating flood peaks and
- dikes.

Non-structural measures include:

- zoning, i.e. regulation of development in flood hazard areas by allowing only low-value infrastructure on the floodplains
- forecasting systems for warning, evacuation, relief and post-flood recovery
- flood insurance, i.e. the division of risks and losses among a higher number of people over a long time period and
- capacity building by improving awareness of the impacts of flooding, an understanding of processes involved and what is implied in flood preparedness.

Forecasting systems hold considerable promise for the future. They may be divided into:

- short-term forecasts, e.g. for flash floods, requiring the use of high technology such as radar or remote sensing as the basis for quantitative precipitation, and hence flood, forecasts and triggering flood action plans
- medium-term forecasts, which include the use of seasonal climate forecasts for reservoir operations, advice on agricultural production and, where applicable, information on snow cover and
- long-term forecasts, which need to be developed for designing flood protection systems.

Finally, it is important to rectify common misconceptions about floods, e.g. that:

- floods occur at semi-regular intervals and
- that floods in the future will be similar to those of the past.

1.6 Droughts

1.6.1 Why do droughts matter?

Droughts have several direct and indirect consequences on human livelihoods. A direct consequence of drought is crop loss, which can, in turn, cause starvation among humans if alternative food sources are not available. Indirectly, water shortage contributes to the proliferation of diseases, as people lack water for basic hygiene. If a drought persists, people are often forced to migrate. This occurred in the Sahel region in the 1970s, where drought persisted for 7 years (cf. Figure in Box 1.4). Finally, drought can inhibit regional development by contributing to a cycle of poverty.

A drought occurs because of a lack of available water. This can manifest itself either through a lack of precipitation *per se,* or from a lack of available soil moisture for crops, or reduction of surface flows below a critical threshold, or of the amount of water stored in reservoirs, or reduced levels of groundwater. The impact of drought on a region depends on the adaptive capacity of the humans or ecosystems to cope with the lack of available water in its various forms. Droughts cause severe crop losses not only in semi-arid regions, but also in well-watered countries such as the Netherlands or Bangladesh.

Semi-arid to arid regions generally display a strong climate variability (temporal and spatial) and hence have to cope with extremely dry situations on a frequent basis. Future climate changes are expected to change the frequency, severity and geographical location of droughts. However, in addition to climate variability and climate change, socio-economic changes generally increase vulnerability of particular populations to drought. For example, socio-economic drivers such as population growth or increasing demand for water per capita or loss of traditional knowledge and practices to adapt to drought or urbanisation, can all contribute to an exacerbation of a region's vulnerability to drought.

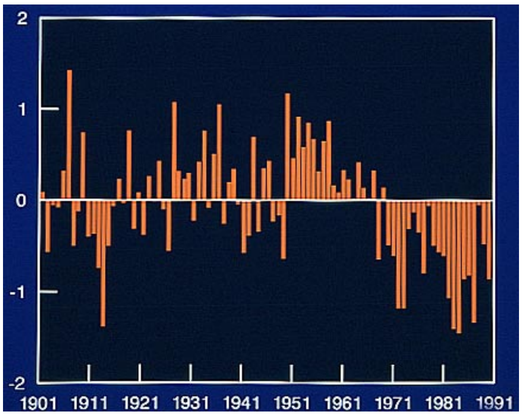
1.6.2 What do we know from the past about droughts?

Droughts have occurred in many places around the world. In the developing world they often bring extremes of human suffering (Box 1.4 and 1.5). In particular, the following countries have been severely impacted by the occurrence of drought (cf. Figure 1.7):

- Afghanistan/Pakistan/India
- Middle East
- Sahel (cf. Box 1.4)
- Northeast Brazil (cf. Box 1.5) and
- Southern and Central Africa.

In the past, it has been the poor who have suffered most from droughts. This will only change if this group can build up adaptive capacity. Unfortunately, the poor are not in a position to influence the mitigation of anthropogenic climate change. It is worth noting that political factors often exacerbate the problem of adaptation. For example, political priorities do not always favour adaptation options such as demand side management. In addition, national self-sufficiency in food production is often a strong priority, requiring that water be subsidised and/or allocated for agricultural production. Finally, many water resources (surface and groundwater) are transboundary and give rise to the possibility of conflicts over water allocation and use.

Box 1.4 Drought in the Sahel



The Sahel is a zone with high variations in averaged annual rainfalls over decades. During the past century, several severe droughts have occurred, including an extraordinarily long-lasting drought, without precedence in the observed climatological record. Significant reductions in precipitation (inset figure; from Sehmi and Kundzewicz, 1997) and, as a consequence, a decreasing flow tendency, have been observed in the past decades over large areas in Africa. For example, since 1970 the mean annual discharge of the Niger River at Koulikoro has nearly halved from its levels in the 1960s. The river virtually dried up at Niamey in 1984 and 1985. The Senegal River at Bakel nearly stopped flowing in 1974 and 1982, and again in 1984 and 1985. The mean annual discharge of the Nile has fallen from the long-term mean of 84 km^3 (1900-1954) to 72 km^3 in the decade 1977-1987, whereas the mean flow between 1984 and 1987 was as low as 52 km^3, with an absolute minimum of 42 km^3 observed in 1984 (Howell and Allan, 1990).

Sahelian populations have been living with drought for millennia, and nomadic and semi-nomadic lifestyles are a traditional way of coping with high rainfall variability. The impacts of drought in the Sahel in recent decades were been exacerbated by agricultural expansion during the wet decade of the 1950s, in which Sahelian governments encouraged people to settle in areas that are usually highly marginal in terms of agriculture, pushing nomadic populations further into the Saharan fringes. When climatic conditions deteriorated in the late 1960s and 1970s, many of these new agricultural areas became unviable, as did a nomadic lifestyle in the still drier areas to the north. The result was famine and conflict, as crops failed and people competed for resources. The deterioration of soil and vegetation by overgrazing, with rising potentials for increased wind and water erosion, is widely cited as a cause of environmental degradation in the Sahel. However, there is no evidence that such processes have caused a systematic deterioration of the Sahelian environment. While population pressure may result in the overexploitation of resources, there is also evidence that it encourages agricultural innovation that can lead to sustainable land management.

Uncertainty concerning the human impact on the environment notwithstanding, Mainguet (1994) proposes a variety of small and specific actions for the gradual rehabilitation of the environment in the Sahel. Among these, the reduction of arable land to those areas with reliable irrigation possibilities is required. The widespread use of solar energy could be considered as an alternative to burning wood. Further drilling of wells for water supply should be restricted. However, the demographic growth in the Sahel region will render any measures to combat drought and desertification extremely difficult. The high vulnerability of the Sahel to climate change is likely to aggravate social and environmental problems (Sokona and Denton, 2001). Awareness building is therefore urgently needed as an area of bilateral and international aid programmes.

In the Horn of Africa, a complex state of emergency may be observed, in which drought interplays with political instability. Long-lasting civil wars in Eritrea, Ethiopia and Somalia hamper the establishment of reliable political systems and the development of stable economies. A prolonged drought threatens those countries' main grain harvest. Large proportions of the vital sorghum crop frequently fail due to drought, and insects damage much of the remainder. Drought-displaced populations in urban centres of Somalia and Ethiopia live under conditions of poor sanitation and hygiene, which have resulted in serious health problems and deaths among children. The repatriation of war-affected Eritrean refugees from Sudan causes enormous problems in handling the large number of returnees. The lack of water, massive land erosion and the presence of landmines, with an alarming increase in mine incidents, hinder the re-establishment of agricultural activities and long-term sustained food production. A large proportion of the population, which produced a major part of the countries' food supplies in former times, now depends on emergency food delivered by international donor programmes.

Even in developed countries an extreme drought may cause considerable environmental, economic and social losses. It is estimated that the 1988 drought in the USA may have caused direct agricultural loss of $US 13 billion. The more recent 1998-1999 drought affected the eastern regions of the USA and the grain growing period in 1999 was the driest on record for four states.

There is evidence that some droughts have been caused by human activities. An extreme example comes from the Aral Sea basin where, due to excessive water withdrawals from the tributaries Syr Darya and Amu Darya, the Aral Sea has shrunk dramatically. However, there has also been a more widespread loss of moisture: in the latter half of the 20th century there has been increased drying out of the land in summer in some areas, increasing the risk of drought.

Box 1.5 Drought in Northeast Brazil

Northeast Brazil has a semi-arid climate, with strong spatial and temporal variations of rainfall. Water scarcity is a major constraint for agricultural production, quality of life and development of that region. Future drought situations might be aggravated by the impacts of climatic change.

In the past the region has been struck by 18 to 20 droughts per century since the 17th century. The population, especially the poor, has been directly affected by the lack of drinking water, food and work. According to some estimates, nearly half of the population of an estimated total of 1.7 million died in the drought-related famine of 1877-1879 (Magalhaes et al., 1988). Nowadays, during drought years, the effects on the population are not that severe as a result of the existence of governmental assistance and emergency programmes. However, during the extreme dry year 1983, there were still a significant number of drought-related fatalities. The economy continues to suffer considerably during drought years, in particular the production of subsistence crops such as beans and manioc. These crops were almost totally destroyed during the extreme drought of 1983, while the total GNP of that region declined 'only' by about 16%.

During the past decades, emergency programmes to combat drought events have proven to be an efficient measure in preventing starvation as well as reducing migration, either to the coast or to Southern Brazil (Magalhaes et al., 1988). However, sustainable development cannot be based on the concept of continuing emergency programmes.

With an increasing population and possibly even higher rainfall variability resulting from climatic change, scarcity of water resources is increasingly constraining development in the semi-arid Northeast of Brazil. An efficient, rational, and sustainable use and management of water resources is, therefore, an imperative in the region. This implies water storage both in small dams, to improve the water availability for the local subsistence farmers, and in large dams, combined with long-distance water diversions for water supply to urban centres (e.g. Recife or Fortaleza) and regions with a very pronounced water deficit. Assessment of water availability and use are key issues within this context.

Taking into account both the internal process dynamics of the causal chain (climate - water availability - agricultural production - quality of life) and the changes of the driving forces (e.g. of climate variability and population densities) requires an integrated and interdisciplinary approach. In a recent joint Brazilian-German research project (Krol et al., 2001) this approach has been followed by means of developing an integrated model to identify sustainable management strategies on a regional scale. With this model, strategies for a sustainable system control are assessed and, under consideration of the interactions, the potential effects of alternative development strategies of social and natural systems are evaluated. First results show that an integrated model can be a suitable tool for complex and interdisciplinary studies by optimising the integrated system under study. However, it cannot produce accurate, or always reliable, results for each of the sector-specific details involved, especially those regarding small-scale processes.

1.6.3 What do we expect for the future?

There are a number of possible reasons for an increase in the frequency and severity of droughts in any particular region (IPCC, 2001):

- There is a growing risk of summer droughts in most mid-latitude continental interiors during the 21st century. Less precipitation and higher temperature may occur simultaneously, reducing available water resources while at the same time increasing evaporative demand.
- As temperatures increase, and evaporative demands from crops and natural vegetation increase, these demands can be met only up to a point, as the consequent loss of water in the soil may not be compensated for by increases in precipitation.
- It is possible that in many different regions of the Earth there will be an increased risk of droughts arising from more frequent and/or more intense El Niño events.
- In many regions changes in the seasonal distribution of precipitation may have even more marked impact upon water resources than changes in total annual precipitation.

The effects of any decrease in precipitation may be amplified through the hydrological system. Runoff in especially semi-arid and arid regions will decrease at a much higher rate than underlying decreases in precipitation, and groundwater recharge and hence groundwater resources may decrease even more than the change in runoff.

Increased climatic pressure will increase the vulnerability of societies and the water related sectors in particular, to other global change processes, notably population growth in areas already at risk, and in particular within developing countries with their more limited adaptive capacities.

1.6.4 What are our information needs?

Meteorological, and in particular hydrological, data are not available at the required resolution and coverages for adequate drought studies. Many monitoring networks are currently in a state of retrogression. Access rights to existing data are often very limited. The capability to distinguish between natural climate variability and climate trends is limited by these data coverages, their quality and issues of access to the data.

1.6.5 How do we prepare for the future?

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 reaction chains.

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. It has caused severe land subsistence in many countries, including Mexico, the USA, Japan, China and Thailand.
- 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. However, this classical drought management policy is becoming increasingly difficult to implement because of its consequences on the environment. For example, when a large upland reservoir storage was created in Thailand, allowing regulation of dry season flow in the upper and middle basin to satisfy domestic and irrigation water demand, upstream activity resulted in a serious decline in water quality, particularly in the lower part of the basin area.

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 for the finite, and scarce, freshwater resource, i.e. seeking ‘megalitres of conserved water’ rather than ‘megalitres of supplied water’. Possible demand-side measures include:

- improved land use practices
- watershed management
- rainwater/runoff harvesting
- re-cycling water (e.g. use of treated municipal waste water 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.

1.7 Concluding Thoughts

- For some regions increases in magnitudes and frequencies of extreme events are being observed now already.
- Future extremes may be even more severe than those, which have been experienced to date.
- Already available short- to medium-term climate forecasts are, at present, not being used in many parts of the world in water management, partly for lack of capacity, but also because the potential has not yet been realised by water managers.
- The greatest scientific barriers to the routine use of information on climate change by water managers lie in the complexity of the scientific tools and the uncertainties that must be accommodated. (There are also substantial sociological and political barriers to overcome.) Methods and media must be developed to overcome those barriers of complexity and uncertainty. This

development will only be accomplished through dialogue between climatologists, hydrologists, and water managers, and only through the allocation of additional resources.

- A paradigm shift is required towards ‘living with floods and droughts’.
- Flood and drought forecasting skills need to be improved over the entire range of time horizons of concern. This is where applied research and technology have a major role to play.
- The substantial advances in weather forecasting needed for flood preparedness have already begun.
- Improving long-term predictability, based on climatic variability and sea surface temperature, emerges as an important tool of drought preparedness.
- Knowledge needs to be enhanced on ‘preparedness of the water systems’, e.g. regarding risk assessment, watershed management (controlling flood generation in source areas) and increasing water storage, to serve both drought and flood protection.
- More and better quality water-related information should be made freely available to all who require it.
- Genuine co-operation must take place between institutions dealing with water, weather and climate, whether they be departments of state, operational agencies or research groups.
- Enhanced knowledge is needed, particularly on the processes of the hydrological cycle in relation to the atmosphere and the biosphere.
- It is necessary to implement a global system, dedicated to addressing scientific issues on assessing the predicted ‘intensification’ of the hydrological cycle and for predicting and monitoring the effects of climate variability and change on water resources.

Chapter 2: Coping with Climate Variability and Climate Change in Water Resources

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2.1 Introduction

Long term changes and increased variability in climate will require that humans develop strategies to adapt to the new conditions. From the perspective of the water resources manager, the question is raised as to how new climatic conditions will affect the strategy of sustainable water resource management. This chapter provides an overview of possible approaches and strategies to coping with, or adapting to, climate variability and change for a wide spectrum of water resources management situations.

Adaptation and coping strategies are not new. Since the time of Noah's flood, societies and civilisations have adapted to the vagaries of climate variability through various coping mechanisms and adaptation strategies. Societies and political systems were organised around the need to control, regulate and distribute water for irrigation and food production. Hence, coping and adaptation strategies are as old as civilisation itself. What are new are the improved technologies that allow for more efficient use of water in industry, households and agriculture, as well as more efficient water management systems (e.g. storage, conveyance, and treatment). In Noah's time it took a providential hint to build a boat in time to escape the flood. Today, people rely on early warning systems and flood forecasts to warn them of an impending flood.

In this chapter the introduction is followed by a brief description on who water managers are and what they manage. The concept of Integrated Water Resources Management (IWRM) is then explored and defined, including some observations on the differences in water resources management between developed and lesser-developed countries (LDCs). In Section 2.4 the challenges that water resources managers face in terms of the spatial complexity and uncertainties involved when coping with climate change are described. Coping and adaptation strategies for water resources management by the water, agricultural and financial sectors are discussed. Given the framework of the Dialogue on Water and Climate (DWC), special attention is given in this section to indigenous coping strategies. Finally, the pertinent recommendations are summarised in the concluding section.

2.2 Who are Water Managers and What do They Manage?

For the professional water resources manager, water management involves the regulation, control, allocation, distribution and efficient use of existing supplies of water to offstream uses such as irrigation, power cooling, municipalities and industries, as well as to the development of new supplies, control of floods and the provision of water for instream uses such as navigation, hydro-electric power, recreation and environmental flows.

Additionally, all levels of government, and especially the private sector and individual stakeholders, are routinely engaged in the management of water. Hence, technically, every individual who uses water is a water manager, from the water resource professional to the woman in the village who draws water from a well. Those who pay for its delivery and treatment are also responsible for its efficient use and conservation. Nevertheless, water managers typically are considered to be those people who are formally trained and involved in some institutionally organised component of water development, delivery or regulation, and who have responsibility and accountability for the decisions that are made.

For the purposes of this discussion, all users, including farmers, are considered to be water managers. In terms of water resources systems, both the large-scale, mostly technical systems, and the small-scale rural systems (including rainfed agriculture) are taken into account. Addressing the adaptation options that farmers in the lesser-developed countries have is particularly critical, owing to the direct impacts climate variability and change could have on their livelihoods.

2.3 Integrated Water Resources Management as Prerequisite for Coping and Adaptation

2.3.1 What is IWRM?

The core of water management has been its historically evolving adaptive capacity and capability. It is redundant to think of adaptation and coping strategies for climate change as something new, or apart, from basic water management practices. Currently, there are no management options that are uniquely suited for adaptation to climate change that would be measurably different to those already employed for coping with contemporary climate variability. The only substantive difference is whether one adopts a more conventional and incremental 'no regrets'[1] approach, or a more anticipatory and 'precautionary'[2] approach. Clearly, water management practices and preferences have changed over time, for example, from 'hard' structures (dams, levees) to 'softer' solutions (floodplain relocation). The range of solutions and strategies has been broadened over time by improvements in technologies and availability of cheaper energy. However, very few of the traditional measures have been discarded from a growing toolbox of management measures of which the utility and cost-effectiveness has been demonstrated in numerous settings.

What has changed is our understanding and implementation of the integrated ensemble of water management measures that conform to modern principles and policies. As shown in Figure 2.1, a catchment is composed of many users, upstream and downstream of one another. The integrated approach considers the catchment as a whole, and 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 best solutions. Rather, they begin planning by asking what the objectives for management are. These usually nowadays include such factors as social and community well being, womens' roles in water user groups and environmental restoration. Integrated Water Resources Management is now the encompassing paradigm for adaptation to contemporary climate variability, and it is the prerequisite for coping with the still uncertain consequences of global warming, climate changes associated with it and their repercussions on the water cycle.

IWRM, like its counterpart Integrated Coastal Zone Management (ICZM), requires the harmonisation of policies, institutions, regulatory frameworks (e.g. permits, licences, monitoring), planning, operations, maintenance and design standards of numerous agencies and departments responsible for one or more aspects of water and related natural resources management. Water management can work effectively

[1] 'No regrets' measures are those whose benefits equal or exceed their cost to society. They are sometimes knows as 'measures worth doing anyway'.

[2] The 'precautionary approach' recognises that the absence of full scientific certainty shall not be used as a reason to postpone decisions when faced with the threat of serious or irreversible harm.

(but not efficiently) in fragmented institutional systems (such as those of the USA, UK and Western Europe), where there is a high degree of transparency in decision-making, public participation as well as adequate financial support being available for planning and implementation. It does not work well in most other cases where these prerequisites do not exist. Setting up the proper institutional framework is the first step towards IWRM (cf Chapter 4).

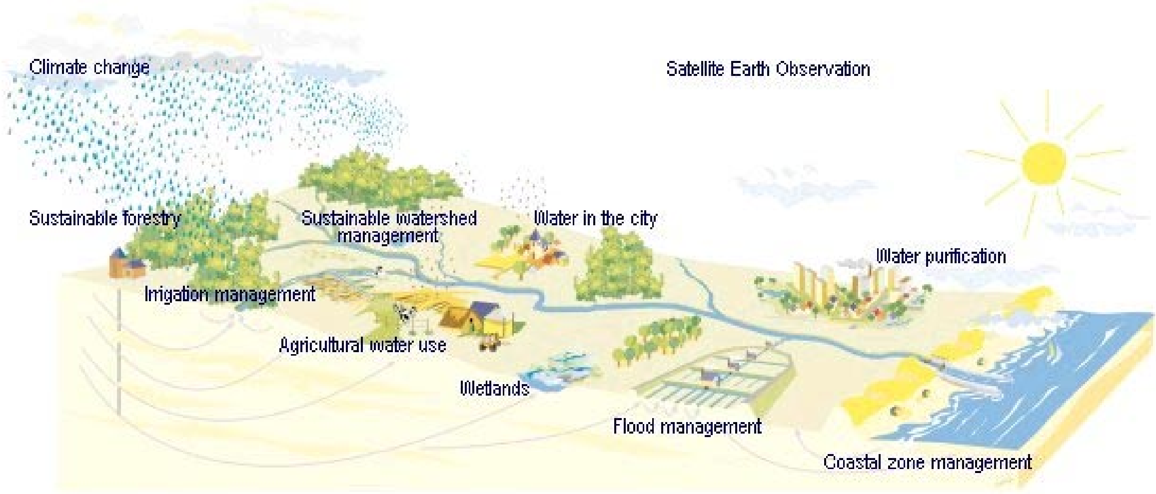


Figure 2.1 Integrated Water Resources Management and Coastal Zone Management (Source: Wageningen Water Impulse; http://www.wageningen-ur.nl/water/).

True IWRM requires at least 5 levels of integration:

- *Vertical integration* ranges from the lowest level of user to the top policymakers in a ministry and all levels of government; from irrigation district to municipality to regional administration to national water commission.
- *Horizontal integration* implies co-ordination and collaboration among all the institutions responsible for resources management at a watershed (catchment) scale.
- *Interdisciplinary integration* involves all relevant disciplines, including socio-economic, engineering, hydrologic, economic and ecological.
- *Functional integration* includes planning, regulatory, design, operations, maintenance and monitoring.
- *Stakeholder integration* involves non-governmental interests, user groups or native groups, in all aspects of water management and decision-making.

Usually the complex, intersecting requirements of IWRM are best managed through a permanent co-ordinating body such as a River Basin Commission or Catchment Management Agency, whose trained staff are versed in both the technical needs of water management as well as in the requirements for multiple layers of co-ordination.

The hallmark of IWRM (and ICZM) is the routine updating and incorporation of fundamental principles for modern water management, as well as improvements in technology. This progressive adaptation of policies, analytical tools and procedures increases the prospects for implementing socially acceptable water projects. It will simultaneously contribute to effective adaptation not only in response to shifting societal needs and preferences, but to climate variability as well, as better and more detailed information and longer hydrological and climate records are incorporated into the planning, design and operation of water resources systems. It is also the constant updating of socially determined management principles and planning objectives that define the evaluation context and rules which allow water managers to distinguish between various management measures and select those which are consistent with the planning objectives established through the public participatory process. These principles have been developed over many decades, and are derived from numerous international conventions. They have been codified as follows:

- Every person should have access to a safe and reliable source of water. Water is essential for food production and self-sufficiency.
- Water is a social and economic good, and its values must be taken into account formally in evaluating projects.
- Public participation is an essential component of effective water resources management and, particularly in LDCs, all attempts should be made to engage women in water resources management.
- Water is managed most effectively at the level for which decisions and responsibilities are routinely exercised (principle of subsidiarity).
- Financial subsidies for water resources development should be minimised and costs should, where possible, be recovered in some form or other by the users to ensure efficient use of water.
- Present-day thinking is that privatisation of selected water resources management functions should be promoted to the extent possible in the developed sectors of economies, especially for vendible outputs and services, such as hydro-power, or irrigation, municipal and industrial water supplies. Privatisation in LDCs can, however, thwart rather than promote the development and well being of the poorer segments of society.

2.3.2 Spatial and temporal scale issues in IWRM

Since catchment processes, including land use and socio-economic processes, take place at a range of spatial and temporal scales, the relevant scale for IWRM is not always clear. As a general statement, however, the appropriate temporal and spatial scales of operation of IWRM are those at which policy-makers, catchment managers and stakeholders of an IWRM plan believe they can achieve their objectives (Schulze, 2002).

In regard to spatial scale, Schulze (2002) lists issues of IWRM for several different scales:

- global scale issues, e.g. water conventions, climate change
- international scale problems, e.g. transboundary rivers
- national issues, e.g. national water management agendas of a country
- catchment scale issues
- local government scale initiatives
- community scale issues and
- household scale problems, e.g. in poorer countries where household food security or household water scarcity are major day-to-day issues.

The larger the spatial scale, the more difficult management becomes, according to Frost’s (2001) observation in rural Africa. A larger scale implies a broader range of resources available, and of the number and diversity of stakeholders who have different skills, interests, resource endowments and management capacities. As a result, agreement and consensus is difficult when spatial scales are too large and plans of action become more complex and time consuming. At very fine scales, however, there is a danger of losing sight of the wider context and of the overall governing processes of IWRM.

Similarly, temporal scale processes can also vary immensely, and need to be considered in the context of IWRM. With respect to the temporal scale Schulze (2002) lists:

- climate scales at decadal, inter-seasonal, intra-seasonal and event time frames, which 'drive'
- river flow scales, which range from multi-year cycles, to inter-seasonal variability, to intra-annual variability, to flash floods
- ecological time scales, which are determined by magnitudes, frequencies and durations of low and high flows as biological triggers
- agricultural time scales, where for crops the intra- and inter-seasonal timeframes are important, whereas for forestry inter-seasonal to decadal timeframes are of significance
- economic time scales, ranging from longer term international to national, regional to local to shorter term individual household time scales
- political time scales, which need to distinguish between essentially stable government structures vs. potentially unstable government structures, as well as distinguishing between inter-election time scales for national to local governance structures
- management and planning time scales, often of the order of 10-20 years and
- wealth/development level time scales, where wealthy countries tend to have longer term planning horizons while for poorer countries they tend to be shorter.

From the above list, it is evident that a wide range of temporal scales exists. The IWRM approach is not committed to one scale, but considers the overlapping time scales in an integrated fashion.

2.3.3 IWRM in developing countries

The DWC is particularly focused on raising awareness in LDCs to the impacts of climate variability and climate change on the water resources. Although the approach to IWRM as described in the previous sections apply to LDCs as well, major differences exist in the way IWRM can be implemented there. Table 2.1 (Schulze, 2002) gives an overview of these differences. Generally, developed countries tend to focus more on quality of life, environment and on long-term issues while LDCs frequently have to address more basic day-to-day issues (Schulze, 2002).

With the tendency for concepts on IWRM and ICZM to emanate largely from the developed world, a re-focus is necessary on problems of IWRM in LDCs. Schulze (2002) states the following generalities for LDCs:

- decisions on water management are often made 'from a distance' in a far-away capital city
- poor peoples' water needs are frequently overlooked or underestimated in broader scale IWRM
- amongst stakeholders there are major disparities in wealth, influence with government, opportunity, skills, resource endowments and capacity for management as well as for economic performance (Frost, 2001)

- government project failures abound because funds have run out, or they are behind schedule, or operation and maintenance are inadequate
- the main need is for basic infrastructure development to provide for water security and
- priorities pertaining to environmental issues are frequently lowered, and where considered, often focus on economic benefits such as erosion and river control

Table 2.1 Characteristics influencing IWRM in more developed versus lesser developed countries (after Schulze, 2002)

Developed Countries	Lesser Developed Countries
INFRASTRUCTURE	
• High level of infrastructural development, with infrastructure generally improving	• Infrastructure often fragile and frequently in a state of retrogression
• Infrastructure decreases vulnerability to natural disasters (e.g. floods, drought)	• High vulnerability to natural disasters: heavy damage and high death toll
• High ethos of infrastructure maintenance	• Low ethos of infrastructure maintenance
• High quality data and information bases available, well co-ordinated	• Data and information bases not always readily available
CAPACITY	
• Scientific and administrative skills abundantly available	• Limited scientific and administrative skills available
• Expertise developed to local levels	• Expertise highly centralised
• Flexibility to adapt to technological advances	• Often in survival mode; technological advances may pass by
ECONOMY	
• Mixed, service driven economics buffered by diversity, highly complex interactions	• High dependence on land, i.e. agricultural production; at mercy of vagaries of climate
• Economically independent and sustainable	• High dependence on donor aid, NGOs
• Multiple planning options available	• Fewer options available in planning
• Take a long term planning perspective	• Take a shorter term planning perspective
• Countries wealthy, money available for planning and IWRM	• Wealth of countries limited, less scope for planning and IWRM
SOCIO-POLITICAL	
• Population growth low or even negative	• High population growth rates and demographic pressures on land
• Generally well informed public with good appreciation of planning	• Poorer informed public, less appreciation of science/planning
• High political empowerment of stakeholders	• Stakeholders often not empowered, afraid to act or to exert pressure
• Decision making decentralised	• Decision making centralised
• High level of expectation of planning and IWRM	• Lower level of expectation and attainment of goals
• Desire for aesthetic conservation	• Need for basics for living

Moreover, for many LDCs, changes in climate and its variability are just one of the many problems they are facing, and depending on the magnitude of these changes, are often not viewed as the most pressing. This should be taken into account particularly when climate change is discussed in the context of LDCs. Also, the ‘solutions’ that come out of the discussions must take the specific conditions of LDCs into account, for example:

- local catchment planning methodologies should be both technically sound and participatory, building on local peoples' (= vernacular) knowledge, experience and practice
- planning initiatives should be accessible to, and involve, local community organisations and which include appropriate capacity building and technical support and
- the framework of initiatives should encourage local-level collaboration amongst NGOs, CBOs (community-based organisations) and relevant government departments.

2.4 Coping Strategies for Dealing with Uncertainties Associated with Climate Variability and Change

Identifying the practical implications of climate variability and change for water resource managers, from individuals to the professional water resources managers, is a difficult task, as the uncertainty surrounding climate forecasts, predictions and scenarios is quite high, increasing with decreasing temporal and spatial scale. This section provides a brief description of the possible impacts of climate variability and change to the water resources, agricultural, and financial sectors, and the corresponding array of coping and adaptation strategies. The section is concluded by a brief description of indigenous coping strategies.

2.4.1 Water resources engineering

Water resources engineers have always dealt, either implicitly or explicitly, with climate variability. For example, both ground and surface water storage help to mitigate against water shortages during dry spells by capturing and storing the water during wet periods. In light of this, Stakhiv (1998) brings the following question to the fore:

The question is whether the current methods of water resource development and management, based on the assumption of a stationary climate, can be suitably employed to accommodate the uncertainties of a non-stationary climate. Several authors, notably Fiering and Matalas (1990), Rogers and Fiering (1990) and particularly Matalas (1997) believe that the framework of stochastic (synthetic) hydrology, that is widely used in project planning, can accommodate the uncertainties in water supplies induced by global warming with the operational assumption of stationarity as meaningfully as with the assumption of non-stationarity.

Gleick et al. (2000) argues that sole reliance on traditional management responses is a mistake:

First, climate changes are likely to produce – in some places and at some times – hydrologic conditions and extremes of a different nature than current systems were designed to manage; second, climate changes may produce similar kinds of variability but outside of the range for which current infrastructure was designed and built; third, relying solely on traditional methods assumes that sufficient time and information will be available before the onset of large or irreversible climate impacts to permit managers to respond appropriately; and fourth, this approach assumes that no special efforts or plans are required to protect against surprises or uncertainties.

Both statements argue that the assumption of climatic stationarity is no longer valid in water resources management. The primary insight from this would seem to be the necessary commitment to a 'no regrets' policy of integrated water resource management, which inherently contains the flexibility and robustness to withstand all but the severest climate change scenarios. In addition, sensitivity analyses conducted on watersheds and river basins under a variety of scenarios may help to refine the operation and design of these systems for even greater resiliency (Stakhiv, 1998). In reference to the above statements, Gleick (2000) stresses that complacency on the part of water managers, represented by the third and fourth assumptions [in the quotation], may lead to severe impacts that could have be mitigated or prevented by cost-effective actions taken now.

Klemes' (1991) list of ways to cope with climate change in water resources engineering includes:

- adherence to high professional standards in proposing solutions to existing water resource problems
- commitment to measures which limit water waste and pollution
- striving for robust and resilient designs
- documenting and taking into account known uncertainties in water supply and demand
- documenting the ranges of feasible operation of a projects, rather than providing only normal design parameters
- providing a general outline of feasible contingency measures for extreme conditions not accommodated by the project under normal operation (flexible operation rules) and
- insistence on clear disclosure of factual information, assumptions and conjectures behind modelling results.

Table 2.2 shows the IPCC adaptation recommendations for water resources managers. Note that there are, indeed, no major changes in coping with enhanced climate variability and climate change compared to what is being done (or should be done) in Integrated Water Resources Management already. The determination of the necessity of these measures will vary depending upon whether or not (and to what degree) climate variability and change are taken into account, i.e. the amount of variability and the level of an unexpected event.

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 permutations for coping with the uncertainties of climate change and variability are limitless – 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 (Box 2.1).

Table 2.2 IPCC recommendations for water resources managers (Modified from Table 4-13; IPCC, 2001)

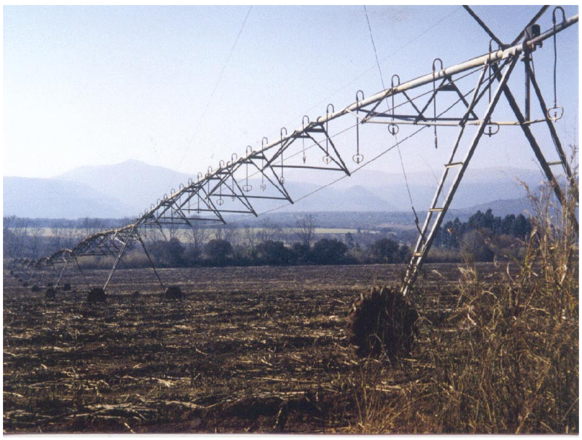
SUPPLY-SIDE		DEMAND-SIDE	
Option	**Comments**	**Option**	**Comments**
MUNICIPAL WATER SUPPLY			
• Increase reservoir capacity	Expensive; potential environmental impacts	• Incentives to use less (e.g. through pricing)	Possibly limited opportunity; needs institutional framework
• Extract more from rivers or groundwater	Potential environmental impacts	• Legally enforceable water use standards (e.g. for appliances)	Potential political impact; usually cost-inefficient
• Alter system operating rules	Possibly limited opportunity	• Increase use of grey water	Potentially expensive
• Inter-basin transfers	Expensive; potential environmental impacts	• Reduce leakage	Potentially expensive to reduce to very low levels especially in old systems
• Desalinisation	Expensive (high energy use)	• Development of non-water-based sanitation systems	Possibly too technically advanced for wide application
		• Seasonal forecasting	Increasingly feasible
INDUSTRIAL AND POWER STATION COOLING			
• Increase source capacity	Expensive	• Increased water-use efficiency and water recycling	Possibly expensive to upgrade
• Use of low-grade water	Increasingly used		
HYDROPOWER GENERATION			
• Increase reservoir capacity	Expensive; potential environmental impacts; may not be feasible	• Increasing efficiency of turbines; promote energy efficiency	Possibly expensive to upgrade
NAVIGATION			
• Build weirs and locks	Expensive; potential environmental impacts	• Alter ship size and frequency	Smaller ships, more trips;increased emissions and costs
POLLUTION CONTROL			
• Enhance treatment works	Potentially expensive	• Reduce volume of effluents to treat (e.g. charging discharges)	Requires management of diffuse sources of pollution
		• Catchment management to reduce polluting runoff	Requires buy-in from farmers, e.g. incentives
FLOOD MANAGEMENT			
• Increase flood protection (levees, reservoirs)	Expensive; potential environmental impacts	• Improved flood warning and dissemination	Technical limitations in flashflood areas and unknown effectiveness
• Catchment source control to reduce peak discharges	More effective for small than large floods	• Curb floodplain development	Potential major socio-political problems
IRRIGATION			
• Increase irrigation source capacity	Expensive; potential environmental impacts	• Increase irrigation-use efficiency	By technology or increasing prices
		• Increase drought-tolerant varieties	Genetic engineering is controversial
		• Change crop patterns	Change to crops which need less or no irrigation

Box 2.1 Adaptation and coping strategies in the Netherlands

A distinguishing characteristic of current Dutch water management is that solutions to water problems are not only sought in technical measures, but also in spatial planning measures. The water management paradigm has shifted from efforts to 'harness' the water towards efforts to 'live with it'. For example:

- *Space for the river* : Human activities are restricted in the watershed in order to create more space for the rivers to flood and roam. Retention capacity of the rivers can be increased by moving the dikes or by widening the floodplains. Creation of branches in areas outside the floodplains will allow the water to diverge from the main stream, thus reducing flood peaks (Rijkswaterstaat Directie Oost-Nederland, 1999; Commissie Waterbeheer 21e Eeuw, 2000a,b).
- *Lakes :* Water levels in lakes are maintained via drainage of water to the sea. As a consequence, higher water tables in lakes require that dikes and dams be strengthened. Water management adapted to climate change should also consider the habitat and regulation functions of the lakes in the Netherlands (Helmer et al., 1996; De Groot, 2000). Desiccation of shallow banks in dry summers (which will occur more frequently due to climate change) is potentially beneficial for development of wetlands. Wetlands in and around the lakes are not only important habitats for flora and fauna, but have also an important 'purification' function (sedimentation of suspended solids and nutrient uptake by vegetation).
- *Maintenance of the coastline by sand supplementation* : This measure is important for the maintenance of the recreational and natural functions of the coastline. Sand losses in the deeper water can also be supplemented. Barrages into the sea can be constructed at in order to aid sedimentation processes.
- *Re-establishment of the natural dynamics of the dunes* : This creates more space for natural dune development. Natural areas (like dunes, coastal salt marshes, peatlands and other wetlands) can function as a sink for sediments (mitigation to soil subsidence) and increase the water retention capacity of the coastal zone by adaptation to reduced freshwater availability caused by sea level rise (Helmer et al., 1996).
- *Development of (rain)water buffering reservoirs in urban areas*: These retain water and reduce flood peaks.

2.4.2 Agriculture



Farmers require buffering capacity in order to cope with the impacts of climate variability on agricultural production. This may require water storage (reservoirs, soil water, and groundwater), as well as increased economic (savings/loans) buffering capacity and, in the case of subsistence farmers, food security. As shown in Table 2.2, the IPCC suggests several supply and demand-side adaptation options for irrigation farmers, which concentrate on high-tech solutions. In the case of rainfed agriculture, farmers are especially prone to the whims of a variable climate. A major obstacle for farmers to overcome is successive years of overly dry and/or wet spells. A poor farmer might overcome a one-year drought followed by a normal year, but a period of two or more years of drought, even followed by a longer period of normal years, will be catastrophic to this farmer.

Farmers have traditionally dealt with risk by spreading their resources. For example, if farmers face the risk of crop failure, they hedge the probability of the risk occurring through some other resource-requiring mechanisms. These could include government programmes, different types of household resource allocations or allocation of resources over the household's lifetime. A more formal way for farmers to better cope with large-scale variability, or catastrophic extremes, is through crop insurance. Abada (2001) notes that despite the seemingly insurmountable odds against government-operated multi-peril crop insurance programmes for the small scale, traditional or subsistence farmers, there is a growing number of specialists who believe that a modified crop insurance scheme for small farmers can be developed and implemented in a viable and sustainable manner. In addition, micro-insurance provides one of the few alternatives to the rural populations and the poor as a means of social protection (cf. Box 2.2).

Box 2.2 A small farmer crop micro-insurance scheme in Uganda (Source: http://www.mcc.or.ug/downloads/agriculture.doc)

Agricultural lending is known to be more risky than providing business loans and hence many micro-finance institutions and even commercial banks rarely give loans to this sector. An initiative by the Catholic community to facilitate access to financial services for Uganda's rural poor saw the formation of the Centenary Rural Development Bank (CERUDEB) as a credit institution in 1983. In Uganda, credit to smallholder agriculture has had a poor record. Two main types of agricultural credit risk are recognised:

- Individual risks – related to the individual borrower, e.g. poor management and crop husbandry
- Specific risks related to agricultural lending, e.g. pests disease, rainfall and prices

The methodology adopted by CERUDEB recognises the above risks and lays down strategies to minimise the risks to manageable levels, for both the bank and the farmer. The main components of this methodology are:

- Analysis at the level of the household unit as a whole, thus not isolating the agricultural project, but rather taking all other cash in and outflows that may exist into account
- Credit analysis, which focuses on the household's repayment capacity, and thus allows for a projection of the seasonal cash flow, over the entire production period and
- Flexible payment plans tailored to the client's expected cash flow, allowing unequal instalments, grace periods, interest payments only, and other types of irregular payment plan.

Experiences from CERUDEB's small and micro loan programme show that constant monitoring and quick reaction to arrears are crucial in maintaining a good quality portfolio. It has been found that they are even more important in agricultural lending, as payments are less frequent. As a result, loan officers have to work even harder than with micro and small enterprise loans. During the tenth month (in 1999) of agricultural lending at Mbale there was a bumper harvest and prices fell drastically, causing difficulties for farmers in loan repayment. In spite of this, the highest portfolio at risk so far recorded has been 6%.

Within the context of water resources, repercussions from the agricultural sector which are linked to climate change relate in the first instance to potential shifts in agricultural belts associated with global warming. These belts are likely to shift to both higher latitudes and higher altitudes, bringing with them a changed partitioning of rainfall into runoff components of stormflows and baseflows, changed total flow regimes and also changed distributions of runoff through the year.

Furthermore, the agricultural sector is likely to impact water resources under climate change through:

- increases in atmospheric CO_2 concentrations (e.g. by reduced transpiration rates caused by increased stomatal resistance)

- increases in temperature (e.g. more dry spells, higher evaporative demand, more frequent irrigation applications)
- changes in rainfall characteristics (where changes in total amounts, seasonality, magnitude per event, convectivity or sequences of wet/wet or wet/dry or dry/wet or dry/dry days will see the need to adjust irrigation scheduling, tillage as well as conservation practices).

2.4.3 Climate forecasting

It is clear that an emerging technology, which has the potential to improve virtually all forms of water management related to climate variability and change, is short-term meso-scale climate and hydrological forecasting for 15-, 30-, and 90-day periods. More reliable short-term weather forecasting for agricultural water management purposes represents a key example of how scientific breakthroughs can aid real-time water management and operations, which in turn improve the overall responses to climate variability and can greatly increase the efficiency of water management and use. This is especially the case for irrigation, which, globally, is by far the largest user of water. Although examples of the use of seasonal forecasts (cf. Box 2.3) and their potential further use, as well as advances in institutional support are cause for optimism, use of climate forecasts by agriculture is, in general, still too new to support the strong generalisations about its value (Hansen, 2002).

Hansen (2002) lists five prerequisites for effective use of climate forecasts:

- Climate forecasts must address a need that is both real and perceived.
- Benefits of forecasts depend upon the existence and understanding of decision options that are sensitive to the incremental information that forecasts provide, and are compatible with decision-maker goals and constraints.
- Forecasts of relevant components of climate variability for relevant periods have to be at an appropriate scale, with sufficient accuracy and lead time for relevant decisions to be made.
- The use of climate forecasts requires that the right audience receives, and correctly interprets, the right information at the right time, in a form that can be applied to the decision problem(s).
- Finally, sustained operational use of forecasts beyond the life of a project requires institutional commitment to providing forecast information and support for its application to decision making, and policies that favour beneficial use of climate forecasts.

Box 2.3 The application of seasonal to interannual climate forecasts based on El Niño-Southern Oscillation (ENSO) events in Brazil

Climate forecasts have been made and utilised since at least 1991 in the Nordeste region of Brazil, where persistent periodic droughts have caused great hardship for poor smallholders and landless peasants. Starting in 1989, the Fundação Cearense de Meteorología e Recursos Hídricos (the Ceará Foundation for Meteorology and Water Resources, FUNCEME) has worked with the state Department of Rural Development (Secretaria de Desenvolvimento Rural, or SDR) in its Planting Time Program, called 'Hora de Plantar' in Portuguese, or literally, 'hour of planting.' The participants in this programme are poor farmers, who register with the agricultural extension service. In exchange for a portion of their harvest, farmers receive high-quality seeds. The extension service does not distribute the seeds until the 'hour of planting' has been declared by SDR on the basis of advice from FUNCEME. This advice rests on the climate forecasts that indicate a likelihood of sufficient precipitation.

The organisation's moment of most visible success came in association with its role in managing the 1992 drought, which was associated with the 1991-92 ENSO event. Warnings were issued in the capital of Ceará, Fortaleza, of potentially severe water shortages, which led government to ration water supplies and construct a new dam (Glantz, 1996). Grain production in 1992 fell only 18%, while only 73% of average precipitation fell. In contrast, grain production fell by 85% in 1987, a year with 70% of average precipitation when climate forecasts were not applied (Golnaraghi and Kaul, 1995). It should be noted, however, that some observers dispute these figures, finding that many farmers save seed from previous harvests rather than obtaining it from state sources, thus limiting the influence of the Planting Time Program (Finan, 1998).

Some well-publicised missed forecasts have eroded FUNCME's credibility in recent years, illustrating the importance of public trust in, and understanding of, the benefits and risks of climate forecasting:

- In 1992, it offered a false negative forecast of drought for 1993, predicting normal rains that did not materialise.
- In 1994, FUNCEME gave a preliminary forecast of drought in 1995. Although it later modified this forecast to a more moderate one, the local perception remained that FUNCEME had forecast drought. When rains fell at moderate levels, some farmers blamed FUNCEME and the Planting Time Program for the income that they lost by planting lower-yielding drought-resistant crops.
- The rainy season early in 1997 proved to be a difficult one to predict. FUNCEME forecasted a year of below-average rains. The rains began early and in normal quantities, leading many people to criticise FUNCEME for issuing an incorrect forecast. This criticism stuck, even though the rains ended in mid-season and FUNCEME's forecast proved correct.

Later in 1997, as the 1997-98 El Niño event began to develop, based on a wide array of information and international agreements, FUNCEME issued a forecast of drought. Despite this international support, the FUNCEME forecast was met with scepticism, since some rain had already fallen, creating the public perception that the rains would be normal. The projected drought did indeed materialise, as one of the most severe of recent years. Although the agricultural and hydrological sectors made relatively little use of the forecast, it seems at least to have restored some of FUNCEME's reputation. The officials in the SDR decided not to wait for FUNCEME's approval before releasing seeds in their 'Time of Planting Program'; they felt pressure from farmers, eager to begin planting with the first rains. Beans and corn production fell by 70%, and rice by 50%.

The rapid transformation of FUNCEME and its early successes were tempered by a series of missed forecasts, which eroded the credibility of the institution. Although FUNCEME has attempted to restore its credibility in the face of dwindling resources, the recent 1997-98 ENSO event indicates that end-users are still not confident in the forecasts (despite their accuracy in this case). This erosion, even with more formalised institutional links to seed distributors, suggests that the public does not accept, or fully understand, the probabilistic nature of forecasts. Further work is required to fully uncover the dynamics underlying public attitudes toward FUNCEME and climate forecasts, and FUNCEME's responses to its erosion of credibility. Frustrated by this public misperception, FUNCEME has decided to limit its contacts with the media, and has begun to rely on press releases rather than interviews and conferences (Maria Carmen Lemos, personal communication).

2.4.4 Indigenous coping strategies

Some 40% of the world's land area is located in environments which are prone to water scarcity. These areas host the hydro-climatic spectrum from arid to dry sub-humid. The major characteristic of these landscapes, often denoted 'drylands', is not necessarily low total annual precipitation, but rather the high rates of potential evaporation experienced and the extreme spatial and temporal variability of precipitation. Coefficients of variation of inter-annual rainfall generally range from 20 – 40%, increasing with lower average annual precipitation. Societies evolving in these environments have, over centuries, developed a broad range of mechanisms to cope with climatic variability.

In rainfed based agrarian communities, which cover large parts of the semi-arid tropical world, this has focused on local development of social, economic and biophysical management strategies to bridge droughts and dry spells, and to cope with floods from intensive storms. The indigenous knowledge base on climatic coping strategies certainly dates back at least 7 000 years, which represents the most recent palaeo-climatic period with more or less constant natural climatic conditions (Nicholson and Flohn, 1980).

Indigenous strategies to cope with climatic variability vary between different geographical locations and between social-religious-cultural settings, as well as between livelihood cores (e.g. between agro-pastoral communities depending on livestock raising compared to sedentary farming communities depending primarily on crop production). It is thus impossible to give a generic overview of indigenous coping mechanisms. Suffice it to state that coping with climatic variability forms an inherent and fundamental part of societies hosted in arid, semi-arid and dry sub-humid temperate and tropical landscapes (Falkenmark and Rockström, 1993).

In a climate change scenario, climatic variability is expected to increase. This, according to several scientists, already has occurred. For example, in the Sahel rainfall averages since 1967 seem to have decreased 10 – 30 % compared to the long term average (Middleton and Thomas, 1992). With prospects of, or even experienced trends of, increased risks of extreme climatic variability, one would expect the proliferation of present and revival of old indigenous coping mechanisms. In general, however, the situation seems to be the reverse. Population pressure, degradation of land and water resources, and migration have, in large parts of the water scarce environments, resulted in a deterioration, and in many cases complete loss, of indigenous coping mechanisms.

From the birth of agriculture until recently in tropical environments (often until the late 19th century or even early 20th century) farming systems were based on shifting cultivation which depended on spatial rotation of cropland and long fallow periods. In environments with large spatial and temporal rainfall variability, this production strategy was strategically designed to spread risks in space and in time. In the Sahel, fallow based rainfed farming has essentially disappeared under the escalating pressure from population growth, and farmers depend for their livelihoods on continuous cultivation on small (far too small) parcels of land. Granaries were used as cereal banks, to store surplus grain from 'wet' rainy seasons for use during dry years, in accordance with Joseph's advice to the Egyptian Pharaoh in the Old Testament (save the surplus from the 7 good years to cope with the 7 dry years which follow). This management strategy, dating back several millennia, formed the backbone of many farming systems in climatically variable environments until modern times.

In West Asia and North Africa coping strategies to deal with climatic variability and water scarcity date back at least to 5000 BC. In Mesopotamia, southern Jordan and the Negev desert, water harvesting systems to collect surface water from intensive rainstorms for use during droughts and dry spells, both for agricultural and domestic purposes, were probably developed simultaneously with the introduction of sedentary societies (Oweis et al., 2001). In a recent study from India (Agarwal and Narain, 1997) it has been shown that water harvesting dates back three millennia BC. These indigenous coping strategies died out during the 20th century as a result of the modernisation of water management during the hydraulic era of irrigation developments. Interestingly, these coping strategies are reviving in pace with the realisation by local farming communities that governments are not able to provide security from climatic variability.

There is a large untapped potential for improving local risk management to cope with climatic variability in many rural societies in water scarce environments. There is, furthermore, scope to transfer knowledge between countries and continents, e.g. on water harvesting for food production in semi-arid regions between West Asia, India, China and Africa (SIWI, 2001). In dealing with water for food within a climate change scenario this is important. Rainfed agriculture is practised on 80% of the global cropland, while 20% is under irrigated agriculture. In sub-Saharan Africa over 95% is under rainfed agriculture. Strategies to deal with climate change in irrigated agriculture are less evident, and include primarily efficiency improvements and decisions on changes in storage capacity in a scenario of increased variability and/or changes in cumulative water flows.

On the other hand, for rainfed agriculture, a much broader set of coping strategies can be adopted and adapted, often based on the transfer of indigenous knowledge between regions. It is interesting to note also that combining coping strategies such as bridging of dry spells with investments in especially integrated soil nutrient management, can result in substantial system improvements, where not only risks are reduced and economic benefits increased (from stabilised growth of yields), but additionally water productivity is enhanced through the increased amount of biomass output per unit of water (Rockström et al., 2001). Overall, this suggests that for risk reduction in rainfed agriculture, in a scenario of climate change, there is at present already a large space for strategic manoeuvring.

2.4.5 Approaches to adapting to and coping with climate variability and change

Determination of the best adaptation and/or coping approach for a specific situation will be based on a thorough analysis of expected conditions, objectives and priorities. Given the complexity of Integrated Water Resources Management, it will often be necessary to follow a systems analysis approach, which includes the following steps:

- formulation of a quantified problem statement
- formulation of objectives and criteria
- description and analysis of the system involved
- prediction of future conditions (bottleneck analysis)
- formulation and screening of measures
- combination of promising measures into alternative strategies
- impact assessment and evaluation of alternative strategies
- sensitivity and scenario analysis and
- decision making.

The manner in which climate change is incorporated in this approach is very specific to the particular situation. If climate change is a minor aspect and has a low priority compared to other aspects involved, it might be that climate change is only included in one of the last steps, *viz.* the scenario analysis. In this scenario analysis the 'robustness' of a particular strategy is then tested for a variety of different conditions. In other situations, climate change can be taken into account as specific meteorological boundary conditions in screening and strategy evaluation, and climate specific measures can be included from the start.

2.5 Concluding Thoughts

- The expected impacts on water resources should be neither under- nor overestimated, but should be assessed in a scientifically rigorous and realistic manner. Only then can appropriate management decisions and adaptation strategies be formulated.
- Tools for water resource managers to cope with climate variability and change are already in existence. These include modelling, forecasting and risk assessments.
- In order to ensure that these tools are applied appropriately, a 'no regrets' approach to water resources management and planning is necessary. In particular, in light of climate change uncertainties the application of the precautionary principle to water resources management within the context of integrated water resources management should be promoted.
- The good news is that coping for present-day climate variability already takes us a long way down the road towards coping for climate change. However, coping with climate variability is, in itself, already a formidable challenge.
- Adaptation and coping measures are scale-dependent and may vary from individual households to local communities to catchment to the (inter)national scale.
- There are fundamental differences which may need to be considered in adaptation and coping strategies between developed and developing countries. For example, for water managers in many developing countries the impacts of changes in climate may be relatively minor compared to the problems they are facing already with present climate variability.
- The adaptive capacity of developing countries is, generally, much lower than that of developed countries.
- As a rule, there is a limit to the resilience of our hydraulic systems and on the capacity of water resource managers to plan and operate for anticipated climate 'surprises'.
- As the ability of forecasts continues to become more accurate, the dialogue between meteorologists and water resources managers must keep pace with these advances in order to ensure knowledge is transferred between the groups.
- Recognising that there is a need for better short- and long-range weather forecasts, the skill level in the current forecasts allows for some optimism in their application. Although examples of use and potential use, and advances in institutional support are cause for optimism, the use of climate forecasting in water resources and by agriculture is still too new to support the strong generalisations that have been made about its value (Hansen, 2002).
- The future of some private sector groups related to the water sector, such as (re) insurance, transportation, agriculture, water supply or municipal sewage treatment systems, could be particularly affected by climate change. Private sectors that traditionally have not cared about water resources management

should envisage the effects of climate change in the near future. The effects will not always be negative. New business opportunities will emerge.

Chapter 3: A Conceptual Framework for Identifying 'Hot Spots' of Vulnerability to Climate Variability and Climate Change

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3.1 'Hot Spots': Regions of High Vulnerability

There has been growing interest by scientists and policymakers on the potential impacts of climate change on water resources. Although it is known that water resources are vulnerable to climate change, the extent of this vulnerability is far from established. Both present climate variability and long-term climate change impacts are, and will be, most severe in the developing world and, first and foremost, affect the poor in these regions. These impacts are widespread, but there are so-called 'hot spots' where they are likely to be particularly severe. These may be countries, or regions or communities within a country, where environmental stress due to climate change and variability is relatively high and where the adaptive capacity to cope with this stress is relatively low.

The key to identifying 'hot spots' is assessing the vulnerability of humans as well as other species and ecosystems to the impacts of climate variability and change. The term vulnerability, however, is very broad, and unstructured classifications of vulnerable areas would quickly lead to an incomprehensible series of locations and regions being identified. Therefore, rather than selecting hot spots based on possible subjective and unbalanced information, it is suggested than an *assessment framework* be used, which allows for evaluating an area, its people and ecosystems in relation to their vulnerability.

This assessment framework uses an independent set of evaluation criteria, which measures the vulnerability, i.e. susceptibility, to climate change. The set of criteria is chosen such that it represents all aspects of vulnerability to impacts of climate variability and climate change. In the context of climate change the Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC, 2001). Definitions for environmental stress and susceptibility are given in Box 3.1.

Box 3.1 Definitions of environmental stress and susceptibility (Alcamo and Henrichs, 2002)

Environmental Stress. Climate-related environmental stress is a function of 'the character, magnitude, and rate of climate change'[3]. In the context of water resources, environmental stress is related to changes in the physical availability and quality of water at a particular location. Hydrological processes, including rainfall, evaporation, groundwater recharge, river flows, wetland and lake levels control this availability. Whilst in some places sufficient quantity of water may be available, it may not be of acceptable quality for the local requirements owing to natural factors, such as arsenic in groundwater, or anthropogenic reasons such as effluent pollution. Climate variability or change may affect water availability and quality directly by altering precipitation or evaporation via temperature. Impacts may also be indirect, such as a change in the vegetation of a river basin, which changes the flux of materials into a river, or changes to ecosystem functions that influence the hydrological cycle.

Susceptibility. The susceptibility of society and ecosystems is a function of a wide range of factors. For example, the susceptibility of a social group depends on its access to water supply, as indicated by the distance to a water source or the time taken to collect water (which will include queuing). Another dimension of susceptibility is the ability of institutions to either respond to the current problems of availability and access, or to cope with future problems, such as reduced water availability or increased variability. Not all countries are, however, equally susceptible. For example, countries such as Saudi Arabia, although subject to a high level of environmental stress, nevertheless have sufficient financial and technical resources to desalinate freshwater from the sea. Thus it would have a low level of susceptibility. The susceptibility of ecosystems has an equally complex set of dimensions.

[3] The quote is from IPCC (2001), but the IPCC did not use it explicitly in connection with the expression 'environmental stress'.

From the above, the question arises whether every ecosystem and every part of society will be equally vulnerable to climate change. The IPCC has already concluded that the answer to this is 'no'. First, climate-modelling results indicate that the intensity and pace of climate change will be more intense in some parts of the world than in others, suggesting that the level of environmental stress will also be different. Secondly, studies of society and ecosystems suggest a great variation in the degree of susceptibility to environmental stress. It follows, therefore, that some communities or societies or ecosystems must be more vulnerable than others. This realisation has led to an interest in 'hot spot' areas of climate change, which can be defined as special geographic areas containing human populations or ecosystems highly vulnerable to climate change. The advantage of identifying hot spot areas is that society can devote more of its sparse scientific and policy resources to these limited areas than to others. Hot spot areas could be priority areas in which society tries to avert, or mitigate, climate-related risks. Other names given to hot spots of climate change are 'critical regions' (Alcamo and Henrichs, 2002), or 'regions of high vulnerability', or 'most vulnerable regions' (Parry, 2000).

3.2 Identifying and Assessing Hot Spots of Water Resources Vulnerability with Respect to Climate Change

Up to the present, relatively few studies have attempted to identify hot spot areas of potential climate change impacts on water resources. An example of a European-scale analysis was carried out as part of the Acacia project (Parry, 2000). The aim of that project was a preliminary assessment of climate change impacts in Europe. As part of its assessment the Project identified the 'most vulnerable regions' in Europe 'where a change in climate would have a substantial impact'. Included in these regions were Southern Europe, because of its increased risk to drought, and Northern Europe because of its increased threat to flooding.

An example of a global analysis was conducted by the IPCC, who identified 'highly vulnerable areas' in their Third Assessment Report on climate change (IPCC, 2001). However, a consistent framework was not used for this analysis. In some cases the IPCC focused on differences between subregions, and in others between sectors. For example, for Asia it identified the relative vulnerability of different subregions (including 'highly vulnerable' subregions) with respect to water resources and other categories of climate impacts. The IPCC deemed the water resources in Central Asia, Temperate Asia, South Asia, and Southeast Asia to be 'highly vulnerable' to climate change. By contrast, for Australia and New Zealand, it compared sectors rather than subregions and reported, for example, that irrigation and metropolitan water supply systems had 'high vulnerability in some areas'.

Another example of a global analysis of hot spots of climate change and water resources was carried out by Alcamo and Henrichs (2002). In their analysis they focused on water scarcity rather than flooding as a problem, and used the term 'critical regions' rather than hot spot areas. Recognising the difficulty of setting universal standards for critical regions, they used four different sets of criteria and four different scenarios of climate change. As an example, one set of criteria specified that critical regions must meet the following conditions:, *viz.*

- they must currently be under 'severe water stress', defined as being where average annual water withdrawals exceed 40% of annual water availability
- water stress must be intensifying between 1995 and 2025 because of growing water withdrawals (related to population and economic growth) and/or decreasing water availability (related to climate change).

According to this set of criteria, and taking into account socio-economic and climate changes up to the 2030s (according to the 'Markets First' scenario of UNEP's Global Environmental Outlook), they identified the following critical regions (Figure 3.1): in North America – the northern region of Mexico and a small part of the southern United States; in Latin America – a small part of its west coast; in Europe – the lower Seine and Rhine, and the lower Don and Volga; in Africa – a large section of South Africa, a part of the Northwest of the continent, and the Nile basin; in Asia – much of the Middle East, northern China, and most of India and Pakistan; in Australia – the Murray-Darling Basin. The total area designated 'critical regions' was 17.2 million km^2, or 13.0 percent of the world's river basin area (outside of Greenland and Antarctica). Some areas are critical because of increasing water withdrawals, some because of changes in precipitation and temperature that lead to decreasing water availability, and some because of a combination of both (a total of 8.7 million km^2).

The analysis of Alcamo and Henrichs (2002) showed the importance of setting thresholds for vulnerability in order to identify hot spot areas. It also illustrated the need to specify future climate and other conditions. In other words, whether or not a 'hot spot area' is hot depends on the selected climate change and socio-economic scenario, and the time period under consideration.

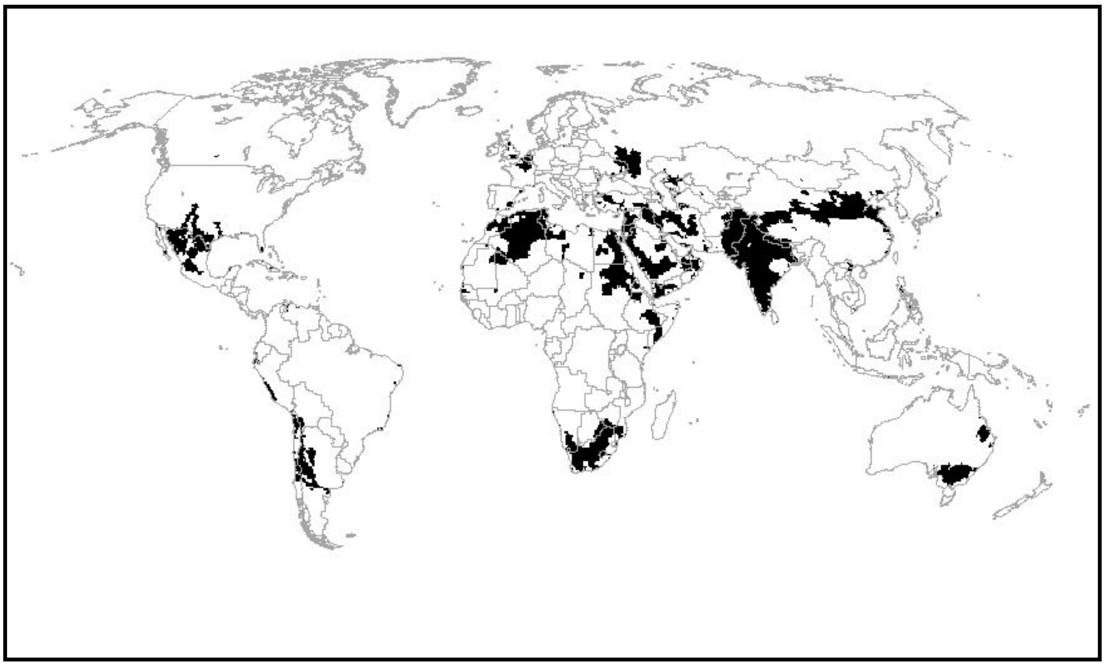

Figure 3.1 Estimate of Critical regions in the 2030s under the climate change and socio-economic conditions of the 'Markets First' scenario (Source: Alcamo and Henrichs, 2002)

An example of a global analysis that compared nations rather than regions is the vulnerability mapping of Lonergan (1998). Lonergan quantified the 'vulnerability' of nations to environmentally related migration and conflict using 12 factors, which include child mortality, income per capita, and 'degree of democratisation'. Each country was then assigned a vulnerability rating based on its average score for these indicators. Lonergan presented his results on a global map which portrays the relative vulnerability of one country versus another (Lonergan, 1998).

A similar global analysis is contained in the World Vulnerability Report being prepared (at the time of writing) by the United Nations Development Programme (UNDP). According to UNDP, the report will highlight the evolution of patterns of risk and vulnerability and promote the adoption of policies, legislation and governance structures for managing and mitigating disasters. At the core of the Report is the estimation of a country-level Global Risk-Vulnerability Index, which assesses countries according to their relative disaster risk levels over time. The index will be presented on global maps.

3.3 Related Research That Can Contribute to Hot Spot Assessment

There is ongoing research in the social sciences that could be very relevant for assessing susceptibility of society to changes in climate and water resources. The political scientists Organski and Kugler (1980) introduced the idea of 'political capacity of states', which is intended to capture 'the ability of political systems to carry out the tasks chosen by the nation's governments in the face of domestic and international groups with competing priorities'. In one application, Organski and Kugler (1980) showed that political capacity was related to the capability of nations to sustain and recover from war. These national capabilities may bear a close relationship to the idea of a nation's being able to cope with climate change.

The disciplines of sociology and psychology have also developed ideas relevant to assessing susceptibility. In these cases, susceptibility has been related to the concept of 'coping capacity'. More specifically, susceptibility is taken as the absence of suitable coping capacities of social groups. Coping capacities are high if people are able to undertake actions that are appropriate in preventing harm from environmental stressors. Although this concept is oriented towards the susceptibility of individuals or social groups, the state also plays a major role in this concept by providing alternatives for an individual to respond to stressful events. A representative example of work is 'Protection Motivation Theory' developed by Rippetoe and Rogers (1987). This theory has been found to be useful in describing coping capacities of social groups facing environmental stress (e.g. Gardner and Stern, 1996).

3.4 Development Needed for Improved Vulnerability Assessment

Despite the attempts made up to now to assess hot spot areas, there is a crucial need to improve the methodology for carrying out these assessments. To develop this methodology one needs to address the main deficiencies of the work already carried out. First of all the meaning of 'hot spot area' needs to be clarified. Are hot spot areas truly *areas,* i.e. geographic areas where populations or ecosystems are most vulnerable, or are they the populations or ecosystems themselves? In other words, are refugees as a social group a 'hot spot', or is a region containing a large numbers of refugees a 'hot spot area'? Furthermore, should we focus on populations or ecosystems, or can sectors such as 'municipal water supply' also be deemed hot spots?

Secondly, the identification of hot spot areas requires further research on specifying the thresholds of vulnerability. Indeed, hot spot areas cannot be specified without first specifying these thresholds. Sometimes they are explicit, as in the analysis of Alcamo and Henrichs (2002) where it was required that a region had to meet two quantitative conditions to be a 'critical region'. But more often thresholds are implicit and not explicitly stated, as in the case of the assessments by IPCC or the Acacia project.

Thirdly, the identification of hot spot areas requires, as a pre-condition, a consistent framework for vulnerability assessment. Such a framework is needed so that one region's vulnerability can be compared in a scientifically credible way with another's. Such a comparison between regions would also provide new insights into general factors affecting vulnerability. Furthermore, a transparent assessment framework would link new studies with ongoing vulnerability assessment studies.

3.5 First Steps Towards a New Framework for Vulnerability Assessment of Water Resources

3.5.1 The suggested framework

The idea of a consistent framework for vulnerability assessment and the identification of hot spot areas is to evaluate the level of environmental stress and susceptibility of a region according to a standard set of criteria (Table 3.1). These criteria are chosen such that they represent many important aspects of vulnerability with respect to impacts of climate variability and change. Criteria for environmental stress are subdivided into indicators related to the quantity of water (i.e. too much or too little or too variable) and its quality. Susceptibility is broken down into indicators of 'access' to actions and infrastructure that can help individuals or ecosystems to cope with climate change, and indicators related to their 'ability' to manage water resources in the face of increased climate change. 'Ability' is a function of financial resources, strong management institutions, and other factors.

Table 3.1 A framework for identifying areas highly vulnerable to water stress

ENVIRONMENTAL STRESS								
Quantity							**Quality**	
Magnitude	Variability	Temporal aspects	Domestic	Food production	Natural resources	Protection	Human health	Ecosystem health
SUSCEPTIBILITY								
Access				**Ability**				
Distance	Legal rights	Price	Infrastructure	Technical	Financial	Social	Institutional	Demographic

3.5.2 Hot spots at different spatial and temporal scales

Spatial scales play an important role in using the vulnerability assessment framework proposed above for identifying hot spots. Some hot spots will be related to entire geographic regions or river basins while other hot spots refer to cities or small scale farming communities. Currently, the framework as presented in Table 3.1 does not distinguish different scales of hot spots and it is, therefore, recommended to use the assessment framework both in a bottom-up approach and top-down (or 'global') view, in order to identify hot spots at all scales.

Accounting for the dynamics of climate impacts over time is important. Some areas already are a hot spot and thus are more vulnerable when compared to other areas in terms of the criteria in the assessment framework. However, external factors may alter the water system, and thus its vulnerability in the (near-) future. These external factors are here referred to as 'driving forces'. They include changes in the social system of an area, demographic changes or economic growth. Climate change itself is, in fact, a driving force. The framework should therefore be used with and without accounting for influences of driving forces – or in other words, one should evaluate a potential hot spot for its current vulnerability and its projected vulnerability within 30 to 50 years.

3.5.3 The river basin as a unit for vulnerability assessment

A river basin, or catchment, may be defined as an area determined by the limits of a specified watershed. It includes both surface and underground water. River basins are open systems with sometimes ill-defined boundaries. This makes them difficult to manage, since political agreements as well as new water legislation of a country cannot always be implemented when it is not clear to which catchment area the policy and law applies. Moreover, trans-boundary river basins fuel controversies on water demand and pollution since the riparian countries are not used to thinking and acting as 'catchment entities' – rather, they perceive a water resource problem from a their own 'country perspective'.

Catchment management is important, however, especially for assessing impacts of climate change and variability on the hydrology of the entire basin. Well known examples of upstream hydrological changes that influence downstream water use and availability are, for example, accelerated glacier melting causing glacial lake overflows, increased storm activities causing flash floods with increased sediment loads and upstream land use changes, which may increase flood and drought dynamics in the downstream parts of the basin.

3.6 Examples of Applying the Framework

3.6.1 The Ganges-Brahmaputra-Meghna Basin

To illustrate an application of the experimental framework for vulnerability assessment, the Ganges-Brahmaputra-Meghna Basin (GBM), shown in Figure 3.2, is examined. The vulnerability of the basin can be qualitatively evaluated with the the indicators shown in Table 3.1. In terms of water quantity, it is projected by the IPCC that the magnitude of the monsoon discharges will increase by 2050, with possible increased effects on flood magnitude and duration in the downstream parts. In the dry period, however, less water will be available according to IPCC scenarios, resulting in drought and possible decreased food production. The quality of ecosystems, such as the mangrove areas at the border of Bangladesh and India, are affected by decreased fresh water discharges in the dry period, and the mangroves are then likely to suffer from increased salt water.

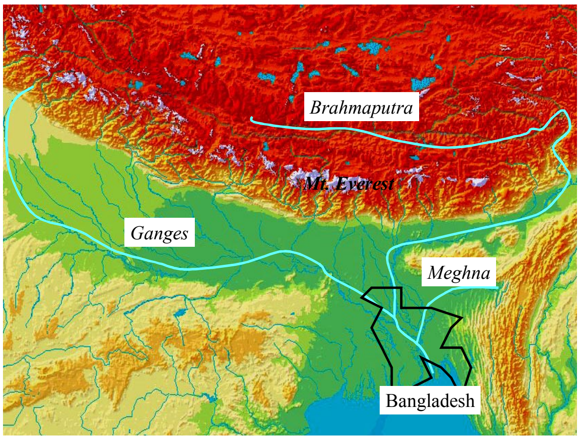

Figure 3.2 The Ganges-Brahmaputra-Meghna Basin

With respect to susceptibility, the institutional framework between the riparian countries in the GBM basin is yet to be developed, and it is currently unable to cope with excessive population increases in the area. For example, the construction of the Ganges barrage at the border between India and Bangladesh has generated political friction for more than twenty years, and thereby inhibits further basin-wide institutional development. However, the first negotiations between India and Bangladesh are ongoing, hopefully setting the basis for a basin-wide co-operation.

3.6.2 Over-abstracted aquifers in the Mediterranean

As another example of applying the above framework for vulnerability, the problem of over-abstracted aquifers in the Mediterranean region is examined. In Mediterranean Europe, irrigated agriculture is the heaviest user of abstracted water and accounts for 80% of total demand in Greece, 50% in Italy and 65% in Spain (Acreman, 2000). Much of this water derives from groundwater, since surface runoff is insufficient to meet irrigation demand. For example, of the 5500 million m^3 abstracted annually from aquifers in Spain, 4000 million m^3 is used for irrigation (Ministerio de Medio Ambiente, 1998). An imbalance between supply and demand occurs occasionally owing to reduced recharge as a result of droughts and other climatic variability, which may be accentuated by future climate change. For example, it is predicted that by 2050 only a slight decrease (5%) in annual rainfall will occur over central Spain with no change in its seasonal pattern, whereas early wet season rainfall is expected to decrease significantly in Greece, with annual totals 25% less than at present.

In 51 of the 442 hydrogeological units in Spain the abstraction/recharge ratio is greater than 1. The Mancha Occidental aquifer abstraction increased from 200 million m^3 yr^{-1} in 1974 to 600 million-m3 yr^{-1} in 1987. This latter figure is greater than the estimated average recharge of 200-300 million-m3 yr^{-1} to the aquifer from the catchment. This has resulted in degradation of large areas of internationally important wetlands, including the Tablas de Damiel. A water law was passed in 1995 to limit abstraction in 15 hydrogeological units, which had been declared over-exploited in 1994.

This water law could, in theory, solve the situation of water exploitation if the regulations were to be applied in aquifers declared as ‘over-exploited’. For these aquifers, the relevant water authority should prepare a water plan indicating the maximum amount of water available to each groundwater-licensed user. In practice, the situation has become much more complicated. Since the aquifer was legally declared ‘over-exploited’, and the authority attempted to impose abstraction restrictions, farmers have drilled an estimated 8000 to 9000 new, but illegal, water wells. Before this declaration, about 16 000 wells had been drilled (Acreman, 2000).

This case study shows a region where water supply and demand are finely balanced and where the authorities are trying to implement sound management measures, but where collaboration with water users is proving the obstacle to sustainable water use.

3.7 Concluding Thoughts

- While our knowledge continues to increase about climate, water and vulnerability, we are still far from being able to reliably identify ‘hot spot’ areas. Here they have been defined as special geographical areas containing either human populations or ecosystems highly vulnerable to impacts of climate change.
- The advantage of identifying hot spot areas is that society can devote its sparse scientific and policy resources to such limited areas. Hot spot areas could serve as priority areas where society tries either to avert, or mitigate, climate-related risks.
- However, in order to make progress in identifying such areas several tasks remain. These include clarifying the definition of hot spot areas, specifying the thresholds of vulnerability, and developing a consistent framework for vulnerability assessment.
- These and related tasks need to be added to the agenda of climate and water research.

Chapter 4: Policy Analysis and Institutional Frameworks in Climate and Water

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4.1 Introduction

This chapter has four main objectives:

- The first (and main) objective is to emphasise, implicitly and explicitly, the evolution and central role of politics in determining water use and water management practices
- the second is to provide a critical review of how societies currently deal with climate variability and Integrated Water Resource Management (IWRM)
- the third is to provide a critical review of water management institutions and political processes in which they engage and
- the fourth is to identify and evaluate solutions which political institutions can take in order to address problems associated with existing and predicted variations in water availability.

In terms of the primary objective listed above, this chapter aims at drawing the attention of the following groups to the political significance of anthropogenic climate change:

- the climate variability/climate change science community
- the water management community
- water policy makers and, ultimately,
- the water users.

It will be shown that science information inputs can influence and shape outcomes. However, such particular knowledge inputs are always subordinate to long established discursive political processes. Only during exceptional windows of opportunity are new ideas adopted quickly, thereby enabling new policy initiatives to be implemented. Extreme, or emblematic, events can open such windows of opportunity. It is normal, however, for a good idea to be subject to between 25 and 50 years of contentious political discussion before it appears as policy. This is true irrespective of whether the science community or a social movement launches the new idea.

4.2 Evolution of a Political Framework for Water Resource Management

Anthropogenically induced climate variability and climate change have been contributing to the discourse on environment and water since the late 1980s. The IPCC process has been remarkably effective in discursive terms. There have been a number of prominent ‘knowledge establishing’ landmarks/milestones, as in Rio in 1992 (Johnson, 1993) and in the Kyoto Protocol of 1997 (UNFCCC, 1997). But, as in any discursive process, there have been setbacks. For example, in 2002 the President of the USA withdrew his commitment to Kyoto and, for a variety of political reasons, the USA stood firm in their position, despite of the voices in the discourse pressing them.

Figure 4.1 illustrates the trajectories of five paradigms in the way water for irrigation has been mobilised and managed over the past two centuries. In the first pre-modern paradigm the capacity to use water was limited. In the second paradigm of industrial modernity, societies became imbued with a sense of certainty through the development of science, engineering, effective bureaucratic government and entrepreneurial capitalism. For example, most people were certain that using more and more water in irrigated farming was a good idea. The end of this phase in the northern hemisphere came with the Green Movement's introduction of the notion that certainty was dangerous. After three decades of discourse there was a dramatic shift in ideas and policy in the 1970s regarding the management of water in the North (Reisner, 1984). Uncertainty replaced certainty and northern communities became intensely aware of environmental risk.

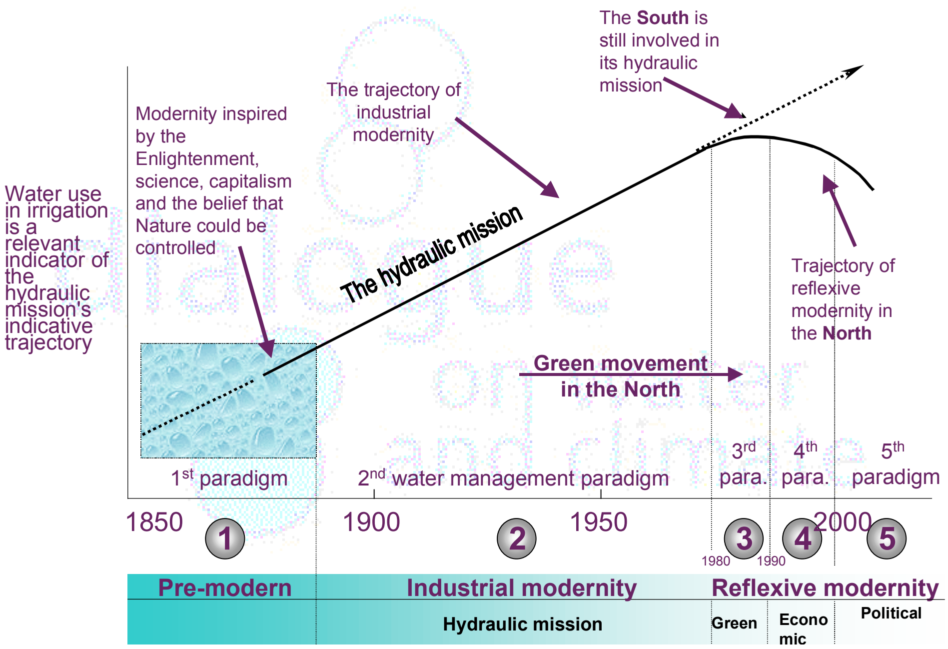

Figure 4.1 The five water management paradigms between 1850 and 2000 (Allan, 2000).

Reflexive modernity is composed of three paradigmatic phases, viz. green, economic, and political. The third paradigm (Figure 4.1), starting in the 1980s in terms of policy impact, was inspired by the green message. As a consequence, much water has been returned to the environment from agriculture. The fourth paradigm, which began in the early 1990s, is characterised by water being considered an economic good. No longer should society be unaccountable for the cost of providing water. In addition, water pricing was seen as a demand management tool, or a technique to make water use more efficient. The fifth paradigm represents the political process of water management. In this paradigm, for example, the quest for food security in the North can be a driving political force in terms of agricultural production, despite the cost of subsidies.

4.3 Critical Review of Present Approaches and Policy Responses with Regard to IWRM

The present unfulfilled demands, mismanagement of water resources and rapidly shifting changes in socio-economic structure, demographics, technology and public preferences pose water management issues and opportunities that generally are greater than those that are forecast to result from climate change. On the positive side, for example, 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. If we did have such systems and policies in place, they would provide resilience to deal with the additional, but largely unknown, impacts of climate change.

There are few countries in the world that have developed comprehensive national water management plans and strategies. In the absence of these, fragmented approaches by a proliferation of government agencies and other stakeholders make implementation of Integrated Water Resources Management difficult, at times impossible. For example, in Canada (as in several other countries) water is considered a natural resource under the jurisdiction of the provinces. The distribution of water resources and the demands vary widely. Legislation on environmental protection and even standards for drinking water also vary. This will make it very difficult for Canada to take positions in negotiating international agreements related to trade and which involve the concept of virtual water or water transfers. In most less developed countries, the policy and institutional frameworks are much weaker still.

There is almost unanimous agreement among water resources managers and the international community on the Dublin and Rio statements on holistic management (ICWE, 1992) and safeguarding basic needs and ecosystems (Johnson, 1993). There probably is no country in the world, however, that has fully integrated them into their policy framework. The degree to which they can be implemented and put into practice depends on the adaptive capacity of countries' institutions. It is not surprising, therefore, that developing countries are even further from reaching the ideal of IWRM than more developed ones (cf. Chapter 2).

In 1993 the World Bank adopted a policy paper that established IWRM as the objective for all of the countries to which it lends capital. In reviewing that policy now, the Bank's staff recognise that many countries are so far from this objective, and are so lacking in adaptive capacity, that the immediate goal of the Bank should be to push for incremental improvements in the policies and institutional capacity. Through a series of such measures, adaptive capacity will then be increased gradually.

In response to water scarcity, the approach that is simplest to implement and meets the least resistance is to increase the production efficiency of water, e.g. by improving irrigation efficiency. This approach will, therefore, be the first choice of farmers, engineers and politicians alike. When this has proved to be inadequate, they will turn next to possible ways of allocating water among users. Somewhere around this time they will likely recognise that in satisfying the needs of society, they have done significant, if not irreversible, harm to the environment. At the next stage they may be forced to recognise that self-sufficiency is not possible, and that water must be imported - either physically (usually not cost-effective) or in ‘virtual’ form through goods and produce from other regions or countries. Each stage in this process is more difficult and involves more actors. Ultimately, the last stage requires international negotiations and co-operation.

The above approach may be described as ‘reactive’. IWRM, however, should be based on an approach that is ‘proactive’, ‘anticipatory’, based on the ‘precautionary principle’, and include the application of preventative actions so that there are ‘no regrets’ throughout the process. If such an approach were taken, it would certainly, as noted above, create the resiliency to deal with the additional complications of global warming. The reality is that the ‘reactive’ approach is still the one that dominates, and is likely to continue to dominate, in the absence of long-term political leadership.

It is often noted that even when policies are in place, they are not implemented because one or more of the parties responsible for implementation fails to follow through. Political will and leadership are required also to overcome this implementation gap.

Up until recently there has been inadequate attention to the implications of the need for water for human uses, especially through agricultural production, and the need for environmental sustainability, i.e. two of the Rio principles. More research and discussion will be required to develop policy alternatives and strategies in order to manage water to meet these competing basic needs so as to reduce the uncertainties and ambiguities surrounding this issue. There are ongoing debates too about appropriate policies and strategies to ensure equitable access to water, especially for the poor. Finally, there still is a need to develop appropriate strategies and policies to deal with floods and droughts, even in the absence of climate change. The same must be stressed for coastal zone management, as there has been inadequate attention to the impact that land-based activities have on these areas which are important to an increasingly large human population that lives in them and the coastal ecosystems that need to be sustained. The sea level rise that is forecast will acerbate the need for policies to address this.

4.4 Institutional Decision-Making on Water and Climate in the North and South

4.4.1 Data and decisions

As a broad generalisation, there is a big gap between the North (i.e. the industrialised, institutionally capable countries) and the South (i.e. poorer countries with non-diverse economics) in terms of institutional capacity. The gap exists in social, economic and political dimensions. The South has many pressing issues to deal with outside of the issues of the impact of climate change on water resources. However, at times the policy makers push these issues if they contribute to their stay in power, especially where the soliciting of votes is involved. This has implications on institutional decision-making on water, climate variability and climate change.

In the South decisions are often made without enough scientific data, due either to lack of the data or to a government's making a decision without the aid of comprehensive assessments. Examples of these are drainage of wetlands in order to set up industries, where the drainage would tamper with hydrological and ecological functions. Even when such systems are modified, no measures are put in place to mitigate the repercussions, such as construction of proper drainage channels. Another example is deforestation in favour of agricultural schemes.

It should, however, be stressed that often the data are not available from the scientific community in time for a decision to be made. In addition, even when they are available, they can often not be easily used by politicians to make decisions.

4.4.2 North-South collaboration and dialogue

Financial support from the North to the South is one of the prime drivers for the South in terms of efforts to cope with climate variability and climate change in water resources management. The North could, through mutual agreements or dialogues, for example, help advise the countries of the South on ways forward. This advice should also involve the concepts of IWRM and definitely include assistance in capacity building. Assistance could, for example, also be through supporting the health sector, while at the same supporting projects in water supply and sanitation. Support could go to other sectors as well, such as climate forecasting and monitoring.

There is a common debate in the North on the need for good governance when referring to assistance to the South. Creating opportunities for people to empower themselves through a bottom-up approach is a sound approach to problems related to climate and water. However, empowerment depends on existing socio-economic and political conditions in a lesser-developed country (LCD). The North must appreciate that in many cases daily survival is more important to the people on the ground than problems that could arise from climate change in the distant future.

Both human and infrastructural capacity in the South is not always adequate to handle extreme water and climate related issues. That infrastructure that is available is often in a state of disrepair. Infrastructure is frequently deteriorating while human capacity may be suffering, either from a brain drain or lack of financial resources and incentives to carry out vitally needed climate- and water-related activities (e.g. data collection, storage and analysis).

4.4.3 National and regional power structures

Differences exist between countries on how decisions are taken. In some countries a bottom-up approach exists in decision-making, whereas in others the local populations are rarely consulted. Projects implemented through the top have, in most cases, not been sustainable. While there is a need for local communities to empower themselves, this should be initiated and facilitated by national governments with some aid from the North and not vice-versa.

Some regional co-operation exists in the South, which could be enhanced even more to influence decision-making in IWRM and climate issues. These include Southern African Development Community (SADC) and the East African Co-operation (EAC). However, when encouraging suchlike initiatives it should be noted that countries working together are often at different states of socio-economic development.

In addition, there may be conflicts, both national and regional, which hinder efforts to come up with common approaches on issues related to climate and water, such as water quality monitoring and assessment.

4.5 Barriers to Success in Current Practices in Water Resources Management

Identification of problems is prerequisite to identification of solutions. There are several barriers that can limit the effectiveness of the role of political institutions in managing the water resources in general, but particularly in light of climate change and variability. These include (Schulze, 2002) :

- Sectoralism within and between the government departments and the fragmented nature of institutional structures, e.g. each with different functions as well as different political goals and each with different stakeholders, with ‘control’ of a water sector often being more important than integration, with poor inter-agency linkages between risk management vs water resources vs irrigation vs land management vs international obligations and with effective strategising on climate change impacts then falling through the cracks
- Lack of clearly defined overall strategies, including management objectives, mechanisms for delivery to enable objectives to be achieved, and being ‘high on rhetoric’ and talk at strategic level and ‘low on action’ on the ground
- Lack of research to assess the resource base with respect to water resources availability and risk, and the value of water in terms of economic production (e.g. $/m^3 water or t/ m^3 water), or consideration of the entire hydrological cycle
- Water being a source of conflict, not only between sectors (e.g. rural vs urban) but also within a sector (e.g. dryland vs irrigated agriculture; commercial vs subsistence agriculture), but in particular with respect to upstream/downstream users and uses
- Deficiencies in information, which can imply insufficient spatial information, and/or a lack of willingness among organisations to share data and information , and/or data/information not collated, out of date or not disseminated because it resides in obscure reports or theses, and/or networks of information flows being inadequate
- Deficiencies in capacity, with regard to human capacity to effect coping strategies on climate variability and change, or capacity being too centralised in certain institutions
- Deficiencies in land management options, including how to use land impacts on quantity and quality of water under variable climate, how to cope with/adapt to changing hydrological conditions with respect to inter-annual climate variability or more permanent climate change, and trade-offs between land use practices, either within a sector and between sectors, in light of climate change
- Lack of willingness to integrate, e.g. with land users and land use agencies each still seeking to assert their primacy in relation to how the land and its associated water resource should be used, or in regard to political power plays existing between individual disciplines involved in IWRM and their distinctive methodologies of seeking solutions to coping mechanisms (e.g. types of and approaches to modelling, or the use of ‘hard’ vs ‘soft’ tools) and
- Lack of audit and post-audit procedures, which embrace, *inter alia,* who is going to enforce and ‘police’ progress in coping strategies as well as who will critically evaluate the performance of actions during and after an extreme event.

4.6 Identification of Solutions

4.6.1 The need for new paradigms

In order to address the above barriers, political institutions need to adopt new paradigms, which include (Pahl-Wostl, 2002a):

- changing the technology-driven tradition of water resources management to an integrated management perspective where the human dimension has a prominent place
- adopting a new and comprehensive notion of policy and polycentric governance that includes the design of flexible and adaptive human-technology-environment systems (of particular importance in times of increasing uncertainty due to climate change)
- bridging the science-policy gap by defining a new role for science as an active participant in polycentric policy processes, rather than being an external observer and
- developing new concepts and methods for public and stakeholder participation in multi-scale integrated assessment processes and modelling.

In order to improve the capacity to cope with climate variability through the political and institutional dimension, a wide range of aspects need to be addressed, involving economic, institutional, social and political aspects. These aspects are worked out in the following sections.

4.6.2 Economic stability and access to markets

As a consequence of climate variability and climate change a wide range of water-related products and services are at risk. The concept of virtual water trade can provide a network to absorb climatic shocks. For countries to take part in the network of virtual water exchange they need to have access to markets and to be part of a system were a minimum of economic and political stability is guaranteed. In the North an example of such a system is the European Union (EU), which developed from a common market into a political union. SADC and ASEAN (in the Far East) have taken similar steps, although the process is not yet as advanced as in the case of the EU.

Economic incentives and market-based instruments play an important role. However, dealing with water as an economic good is not free of controversies. For example, there is a major difference whether water is required for survival or if it is used for leisure purposes. The lack of access to financial resources and market power should not prevent underprivileged groups in a society from their access to water as an essential resource.

Water is distributed unequally among the regions of the world. Whereas water markets and participatory water resources management (through, say, water user associations) may be quite efficient at allocating water among different competing demands on a regional scale, water is not a commodity that can be traded at a global scale. Here the importance of virtual water comes into play. The supply of the megacities of the world will have to be based on a global supply network. Given the potential and/or the perceived increase in vulnerability that may arise from the dependencies in global supply networks, resolving this issue will require a multi-scale participatory process with numerous stakeholders involved.

4.6.3 Institutional capacity for water management

There is a need for a community of water professionals that is fully conversant with the concepts of IWRM and which operates within a network of stakeholders, officials, researchers and educators. A good example of such a network is WaterNet in southern Africa. WaterNet has a joint education, research and training programme in IWRM with about 20 participating institutions from within the region. An important innovation is the modular IWRM Masters Degree Programme that is shared between the universities of the region, which feed the network with a new generation of international professionals. At annual assemblies topical issues are discussed between politicians, researchers, professionals and stakeholders.

Such networks of institutions and individuals can be powerful mechanisms to plan coping strategies for, and thereby absorb shocks related to, water and climate related issues such as floods, droughts, pollution hazards and allocation conflicts. Often, it takes a major catastrophe to stimulate the creation of such a network (Box 4.1).

Box 4.1 Example of policy changes following a flood: The Mississippi-Missouri case

> The Great Flood of 1993 in the Mississippi-Missouri system has been labelled as the most devastating deluge in the recent history of the USA. Historical flood records on the main stem of the Missouri were broken at several observation stations by up to 1.2 m. In St. Louis on the Missouri, the previous record stage was exceeded for more than three entire weeks (cf. Natural Disaster Survey Report, 1994). The Great Mississippi Flood had significant impact on flood policy. The recommendation of the US Interagency Floodplain Management Review Committee after the 1993 flood was that federal, state and local governments and those who live or have interest in the floodplain should have responsibility for development and fiscal support of floodplain management activities (cf. Galloway, 1999). The Committee recommended that the administration should fund the acquisition of needed lands from willing sellers and the buyout of structures at risk in the floodplain. The number of families relocated from the vulnerable floodplain locations in the Mississippi Basin and in other regions in the USA is of the order of 20 000 (Galloway, 1999).

4.6.4 Participation in water management

The process of water resources planning and decision making should be shared with the four main stakeholders in society: civil society, the private sector, NGOs and the relevant government entities. Only if these four groups of actors are actively involved in a participatory process can the process become efficient in addressing the challenges in water resources management.

It is imperative that participation addresses needs and aspirations of both stakeholders and the public at large. Stakeholders should be distinguished from the public at large. A stakeholder is only defined in reference to a particular issue. Public and stakeholder participation has to be based on careful analysis of the current institutional setting (the roles of different stakeholder groups, formal and informal rules, and types of organisation) and a subsequent design of a participatory process.

The participatory process contains certain formal relationships, e.g. public authorities that have formal, legal and/or contractual relationships. In particular, however, it must address groups that communicate only informally, or do not generally communicate at all, but who are affected by an integrated management approach. The latter participatory process will have to proceed with the implementation of novel policies and/or institutional settings. Any water resources management plan that includes environmental, economic and social objectives, as well as changes in technological and institutional settings, has to be developed in a participatory setting. This will guarantee that those issues relevant to the actors are captured. Additionally, the participatory process must take into account the importance of procedural implications, e.g. that the preferences regarding an outcome of a decision are highly dependent on how the decision was derived (Joss and Brownlea, 1999).

Co-operation will play an important role. The importance of co-operation and the difficulties in achieving it have been on the research agenda of the social sciences for many years already (key phrase: ‘tragedy of the commons’). It is now well recognised that trust, reciprocity and reputation are norms that have to be shared by a collective of actors in order to achieve voluntary agreements, engage in co-operative action, adopt novel strategies and escape from situations of social dilemma (Ostrom, 1990; 2001).

The lack of information and the lack of an ability to make decisions often prevent citizens from becoming more involved. In contrast, empowerment implies that citizens really take an active role in defining an issue. This active role embraces a number of important points:

- Citizens need access to comprehensive and timely information about an issue.
- Different perspectives and uncertainties on the issue must also be provided.
- Citizens have to be enabled to take over responsibility in important decisions.
- Institutional settings must permit citizens to phrase and communicate their perspective and to articulate their voice clearly.
- Citizens must have a real stake in an issue to be motivated to make an active contribution.

Citizens should be involved in different arenas of decision making in water resources management. On the one hand, they may participate in making choices on transformation processes towards entirely new management schemes. On the other hand they may become active participants in daily management practices. Hence, one can make a distinction of three different areas for citizen participation (Pahl-Wostl, 2002b), *viz.*

- *integrated assessment*, where informed citizens judge risks and benefits of different development trajectories and management schemes
- *technology assessment*, where single technologies and their risks and benefits are judged and
- *risk management*, where citizens take an active role in assessing and managing risks on a routine base.

4.6.5 Information sharing and awareness

For politicians to become fully committed to the issues at hand, they and the public should be provided with an awareness on the importance of the issues, and with unbiased information on the extent and complexity of the problems. In northern societies there is no lack of awareness, often rather the reverse. However, in developing countries access to information and the awareness of the public is frequently reduced. As a result, the issues on climate variability and climate change are often not recognised as being politically important. There is a need for better sharing of information and access to media.

4.6.6 The facilitating role of government

Governments should share the burden of managing the resource with the other actors in society, particularly with civil society, the private sector and NGOs. Government should be the director of this process, taking on the roles of:

- *Caretaker*, responsible for the conservation and wise use of the natural resources
- *Regulator*, to safeguard the public interest and to enforce the law and
- *Facilitator*, to facilitate that the other actors play the role they need to play.

Concepts of good governance are important aspects in this regard, through the provision of legal security, transparency, accountability and the freedom to express one's views.

The role of water policy in the light of an integrated management of water resources at different scales implies the need to manage major societal transformation processes towards sustainability. In such cases, it is important to adopt a broad understanding of a polycentric policy making. Polycentric governance involves processes of social learning that are essential for processes of innovation and the adoption of new strategies in heterogeneous actor networks (Pahl-Wostl, 2002b).

This implies that a command and control approach that characterised environmental policies in a number of countries (including some in the EU) in the past has to be replaced by the use of market-based instruments in combination with incentives for self-organisation and public participation. This also reflects a changing role for the government and is now characterising the new European Water Policy (Philip, 1998).

Finally, government should promote the development of coping strategies by supporting research, pilot projects and mainstreaming good management practices.

4.6.7 Co-operative agreements

Co-operative agreements between farmers, bulk water suppliers and nature conservation bodies can act as an instrument to meet both environmental standards and economic efficiency.

4.7 Challenges and Recommendations

4.7.1 The political debate on ‘the poor’

The tragedy of ‘the poor’ is linked strongly to the access to water. The poor generally live in a critical balance with the water resources available. For that reason, the people who are most vulnerable to current climate variability are the poor. In the context of long-term climate change and possibly enhanced climate variability, it is once again the poor who will suffer most. Whereas in the rich regions of the world, people have a relatively large coping capability, in developing countries a small change in climate variability (i.e. slightly higher frequency of extreme events or a slightly shorter growing period) can have very large effects in terms of food and water security, health, mortality and economic well-being.

By affecting climate, and hence climate variability, the rich may affect themselves, but more and in particular the poor. The political issue that thus emerges is which mechanism one can put in place to ‘institutionalise’ the responsibility of the rich (North) towards the poor (South). On the one hand, this responsibility can be translated into international agreements on the reduction of greenhouse gas emissions. That has to take place particularly in the North. On the other hand, the North should take the responsibility to contribute to demand-driven institutional capacity building in the South, albeit in a non-patronising way, in order to help increase the capacity in the South to cope with impacts of climate variability and climate change.

4.7.2 The political debate on climate change

Climate change is likely to have global effects in terms of changes in climate variability, but vulnerability to such changes is likely to be much larger in the South than in the North. The global debate on climate change and the strong global institutional framework that has grown around this debate is a good starting point to increase awareness amongst politicians on the issue of availability and access to water in relation to climate variability. This appears to have been achieved with a large measure of apparent success at the 2002 Johannesburg World Summit on Sustainable Development.

4.7.3 Institutional capacity building

Adequate coping with climate variability, in particular, requires that proper institutional frameworks be in place. Institutional capacity building is needed at various levels. At the global level, the current institutional setting for trade between nations is not well prepared to addressing problems that evolve from changes in climate variability. Poor countries are not well represented in, for example, the World Trade Organisation (WTO) debates and they suffer at the hands of high food subsidies in many of the rich countries. Although a free global market can offer opportunities for developing countries, it also carries great threats if vulnerable regions are not well prepared or protected. At the national and sub-national levels, institutional frameworks are also often insufficient. Again, particularly developing countries are usually insufficiently prepared.

4.8 Concluding Thoughts

The political and institutional dimensions are probably the most critical elements in coping with climate variability and climate change in water resources management. The world's political leadership, with the support of international financing agencies, should invest in capacity building in the South to help mitigating the impacts of climate variability and change. Two specific points are, nevertheless, highlighted:

- Concerted action, effectively co-ordinated across the various water use sectors, is required. A number of institutional and organisational issues have been identified to strengthen the preparedness systems, such as enhancing co-ordination, and drawing up clear divisions of competence, tasks and responsibilities among different agencies acting in watersheds (rather than being

bound only by administrative divisions) and assuring participation of stakeholders in decision-making.
- Further dialogue is needed on the equity issues. Lesser-developed countries do not always have adequate financial and human resources and cannot always cope with hydrological extremes without some form of foreign and international assistance. Increase of effective assistance to the lesser-developed countries is badly needed.

Overall, however, the Dialogue on Water and Climate faces the challenges of:

- involving the South more seriously in the debate on impacts of climate variability and change on water resources
- involving the various actors, such as stakeholders, civil society, NGOs and governments, in the debate and
- providing different platforms for dialogue and discussion, which are tuned to the particular needs and interests of the various actors.

Appendix A: Summary of Findings from IPCC (2001) Reports on the Theme of Water and Climate

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A.1 Preamble

This summary contains the main findings from the Intergovernmental Panel on Climate Change (IPCC) reports, on the influence of climate change on hydrology and water resources. These findings are described in the Third Assessment Report (TAR), which was issued in the second quarter of 2001. Most of the descriptions below are taken from Chapter 4 (Hydrology and Water Resources) of Working Group 2 (Impacts, Adaptation and Vulnerability) and from the summaries of Working Group 1(Scientific Basis). The IPCC reports can be found on the website http://www.ipcc.ch.

A.2 Introduction

It has been widely recognised that changes in the cycling of water between land, sea and air could have significant impacts across many sectors of the economy, society and the environment. Consequently, there have been many studies which have focused on the effects of climate change on hydrology (cycling of water) and water resources (human and environmental use of water). The majority of these studies have focused on changes in the water balance. Other, but fewer, studies focused on impacts of climate change on water resources (reliability of water supply or risk of flooding) and explored possible adaptation strategies.

It is important to realise that climate change is only one of the pressures facing the hydrological system and water resources. Other global changes, such as land use changes and land management, similarly threaten the hydrological system. In general, there is an increasing move towards sustainable water management and increasing concern for the impacts of global change on the water resources system. Recent initiatives to address these issues are, for example, the 'Dublin Statement' in 1992, which urged the sustainable use of water, reports on freshwater resources by the UN Commission on Sustainable Development (WMO, 1997) and activities by the World Water Council, which led to a vision for a 'water secure world' (Cosgrove and Rijsberman 2000).

A.3. Current State of Climate Change and Water Research Since the IPCC's Second Assessment Report of 1995

Since the IPCC's Second Assessment Report (SAR, 1995), considerable advances have been made in field measurements, co-ordinated research programmes (e.g. through the IGBP) and in hydrological modelling. Many studies explored and emphasised the role of climatic variability on hydrological behaviour. The hydrological changes over time are acknowledged as extremely important, and knowledge on these changes helps to efficiently develop adaptation strategies. Therefore, the TAR of 2001 emphasises that the hydrological baseline cannot be assumed to be constant.

Planned adaptation to changing climatic circumstances is based on minimising risk and reducing vulnerability. Hence one can distinguish between supply side strategies (e.g. building reservoirs) and demand side strategies (e.g. changes rules for existing structures) as coping mechanisms.

A.4 Climate Scenarios

For the TAR, the IPCC prepared a total of 40 emission scenarios. These scenarios were based on the emission driving forces of demographic, economic and technological evolution, which produce greenhouse gas and sulphur emissions. On the basis of these emissions, possible future pathways of temperature, precipitation and sea level changes have been modelled. Note that none of these scenarios assumes explicitly the implementation of the United Nations Framework Convention on Climate Change (UNFCCC) or the Kyoto Protocol targets.

Four scenario ‘storylines’ were developed (the list below has been adapted from IPCC TAR, 2001, Working Group I Box 9.1, p. 532):

- *Storyline A1:* This scenario describes a future world of very rapid economic growth, global population that peaks in the mid 21st century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. This family is divided into three groups that are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil sources (A1T) and balance (A1B).
- *Storyline A2:* The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented than in other storylines.
- *Storyline B1:* The B1 scenario describes a convergent world with the same global population as the A1 scenario (population that peaks in mid-century and declines thereafter), but with rapid change in economic structures towards a service and information oriented economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.
- *Storyline B2:* The B2 scenario describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with a continuously increasing global population, at a rate lower than that in the A2 scenario, with intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the B2 scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

The computed resulting emissions of CO_2 and SO_2 according to the above-mentioned scenarios are shown in Figure A.1.

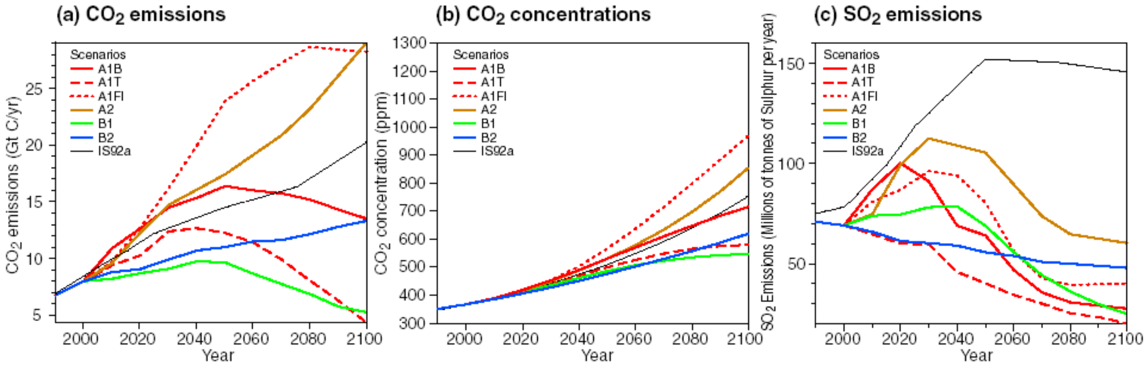

Figure A.1 Greenhouse gas emissions according to different scenarios (IPCC, 2001)

A.5 Climate Modelling

For climate projections, both simple climate models and coupled Atmosphere Ocean General Circulation Models (AOGCMs) were used for the TAR. Because of computing limitations, only the so-called 'draft marker scenarios' A2 and B2 were used for AOGCM model runs. The results from the simple climate models for all 'marker' scenarios (which are considered the most illustrative) are shown below in Figure A.2. The globally averaged surface temperature is projected to increase by 1.4 to 5.8 ºC over the period 1990 to 2100. Global mean sea level is projected to rise between 0.09 and 0.88 m from 1990 to 2100 for the emission scenarios assumed.

In the Figures A.2 and A.3, for six marker scenarios, both temperature increases and sea-level rises are shown for the period 1990 to 2100. The bars at the right of Figure A.2 indicate ranges.

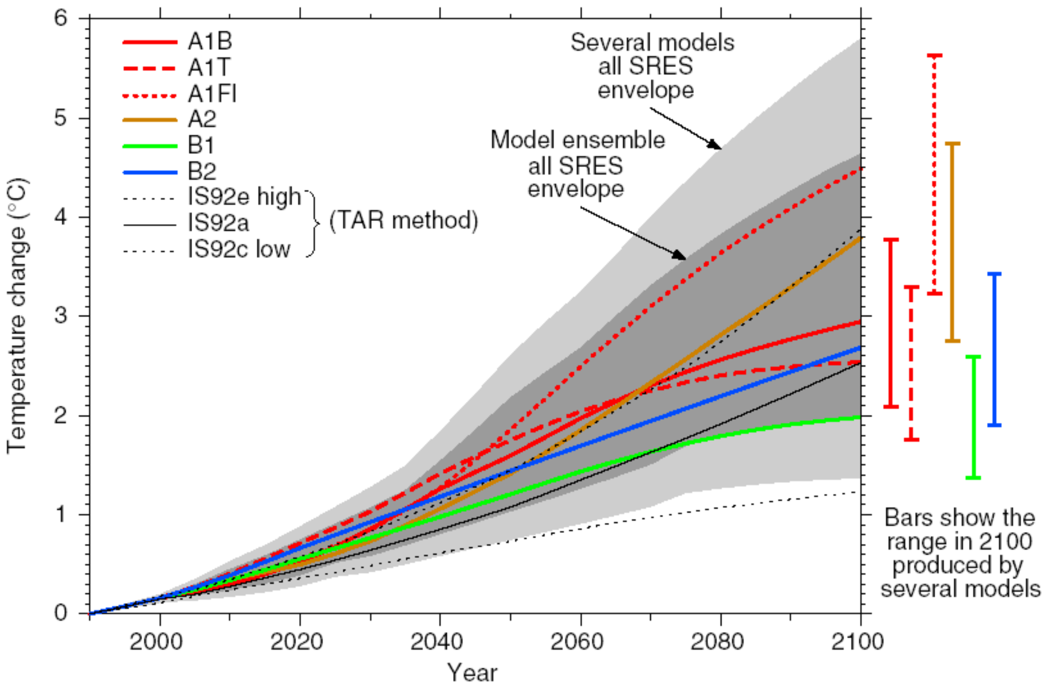

Figure A.2 Global temperature projections, according to different scenarios (IPCC, 2001)

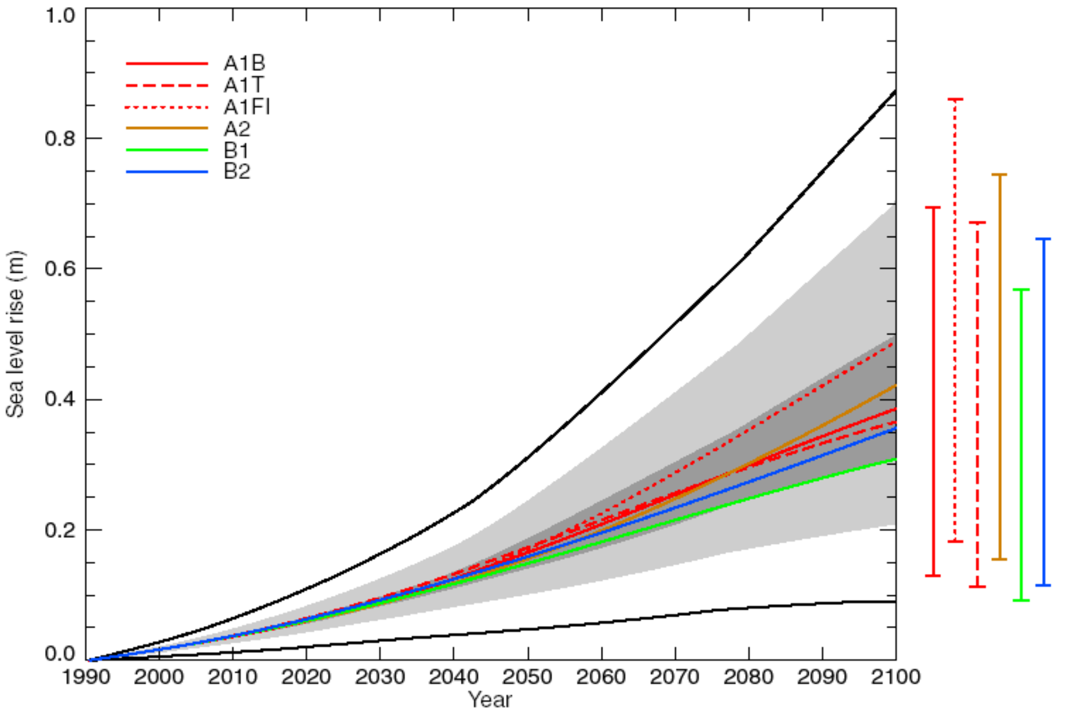

Figure A.3 Global sea level rise projections according to different scenarios (IPCC, 2001)

Furthermore, regional precipitation patterns have been modelled by AOGCMs under the A2 and B2 scenarios. The results and the analysis of inter-model consistency in regional precipitation change are shown in Figure A.4. Regions are classified as displaying either agreement or disagreement on precipitation change. A consistent result from at least seven of the nine models used here is deemed necessary for agreement. Where there is agreement, large increases imply changes of more than 20% in regional precipitation. Small increases lie between 5 and 20% and no changes between –5 to +5%. A small decrease lies between –5 and –20%, and a large decrease is defined as less than –20%. For results where there is no agreement, Figure A.4 shows the inconsistent sign.

A.6 Effects on the Hydrological Cycle

The impacts of climate change on hydrology are usually assessed by defining scenarios for changes in climatic inputs to a hydrological model. These scenarios are derived from the output of general circulation models (GCMs). Problems arise, however, when downscaling GCM results to the scale of inputs used by basin scale models. In effect, the greatest uncertainties in streamflow results from hydrological models using climate change scenarios are caused by the fact that the precipitation patterns from the coarse gridded GCMs are uncertain.

A.6.1 Precipitation

The TAR summarises precipitation trends as a general increase in mean annual precipitation in the Northern Hemisphere (autumn and winter) and a decrease in the (sub-) tropics in both hemispheres (cf. Figure A.4). The frequency of extreme rainfall is likely to increase with global warming, although the spatial resolution of global climate models is too coarse to provide details. Higher temperatures imply that a smaller proportion of precipitation may fall as snow.

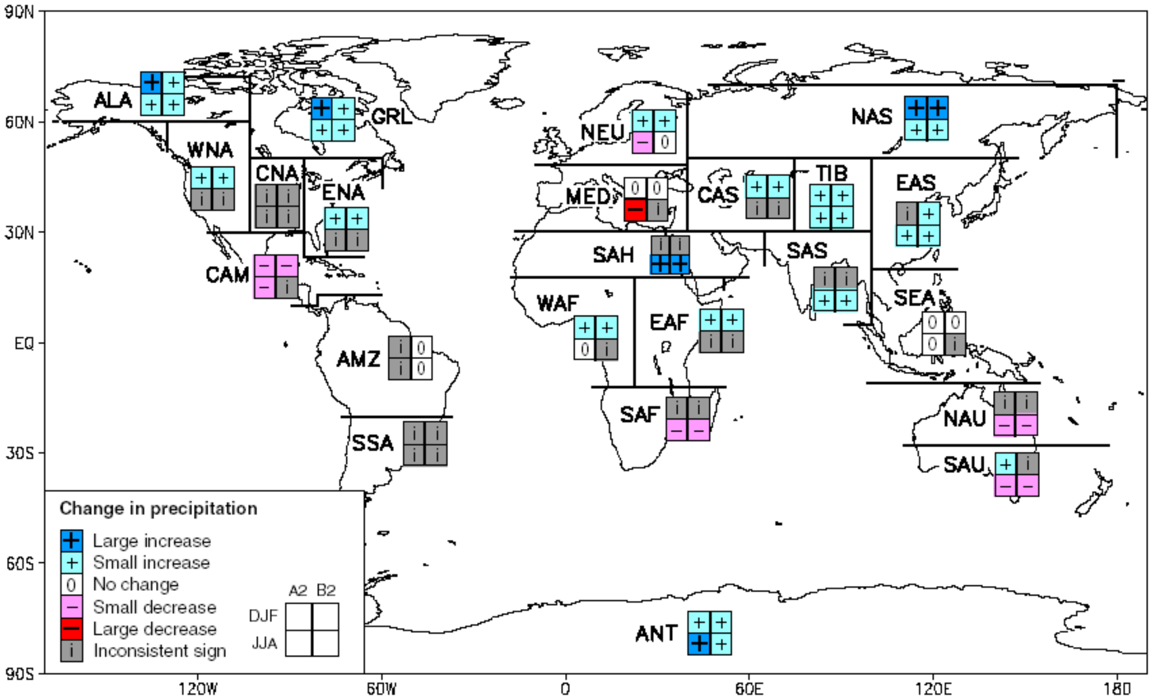

Figure A.4 Projected future changes in precipitation patterns, according to different models. (IPCC, 2001)

A.6.2 Evapotranspiration

Increased temperatures generally result in an increase in potential evaporation. In dry regions, potential evaporation is driven by energy and is not constrained by atmospheric moisture contents. In humid regions, however, atmospheric moisture content is a major limitation to evaporation. Studies show increases in evaporation with increased temperatures. However, models using equations that do not consider all meteorological controls may give very misleading results.

Vegetation plays an important role in evaporation, partially by intercepting precipitation and partially by determining the rate of transpiration. Higher CO_2 concentrations may lead to increased Water Use Efficiency (WUE), i.e. water use per unit biomass, implying a reduction in transpiration. However, higher CO_2 concentrations may also be associated with increased plant growth, compensating for increased WUE. Plants may thus acclimatise to higher CO_2 concentrations. The actual rate of evaporation is constrained by water availability.

A.6.3 Soil moisture

Runs with the HadCM2 GCM show that increases in greenhouse gases (GHGs) are associated with reduced soil moisture in the Northern Hemisphere summers. This is the result of higher winter and spring evaporation, caused by higher temperatures and reduced snow cover, and lower rainfall during the summer. The lower the water holding capacity of the soil, the greater the sensitivity to climate change.

A.6.4 Groundwater recharge

Increased winter rainfall may result in increased groundwater recharge in the Northern Hemisphere. However, increased temperatures may increase the rate of evaporation, which leads to longer periods of soil water deficits.

Shallow unconfined aquifers along floodplains in semi-arid and arid regions are recharged by seasonal streamflows and can be depleted directly by evaporation. Changes in the duration of flow in those streams may lead to reduced groundwater recharge. Sea level rise could cause saline intrusion to coastal aquifers, especially in shallow aquifers. An overlying bed that is impermeable, on the other hand, characterises a confined aquifer and local rainfall does not influence the aquifer.

A.6.5 River flows

Most hydrological studies on the effects of climate change have concentrated on streamflow and runoff. Streamflow is water within a river channel, whereas runoff is defined here as the amount of precipitation that does not evaporate. In general, changing patterns in runoff are consistent with those identified for precipitation. However, in large parts of Eastern and Northwestern Europe, Canada and California, a major shift in streamflow from spring to winter has been associated with a change in precipitation, but more particularly with a rise in temperature, because precipitation has fallen as rain, rather than as snow in winter periods. In colder regions, no significant changes have been observed.

It is difficult to identify trends in hydrological data. Records are short and monitoring stations are continuing to be closed in many countries. However, there are many hydrological models which simulate river flows using climate change scenarios derived from GCMs. Relatively few studies have been published for Africa, Latin America and South East Asia. Responses in different hydroclimates may be quite different. The following four examples illustrate this:

Cold and cool temperate climates: The streamflows in these areas are largely dependent on melting snow in springtime. The most important effect of climate change is the timing of streamflow. There will be more runoff during winter because less precipitation falls as snow.

Mild temperate climates: These regions are dominated by rainfall and evaporation. The magnitude of the flows is determined largely by rainfall changes. Trends show a decrease in summer runoff and an increase in winter runoff.

Semi-arid and arid regions: Here a small percentage of change in rainfall causes considerable effects in runoff.

Tropical regions: Runoff responses are largely dependent on rainfall. The number of extreme events causing flooding may increase due to increased intensity in precipitation.

A.6.6 Other Hydrological Responses

Some other hydrological responses to climate change are given below:

Flood frequency: Relatively few studied have assessed climate change effects on flooding frequencies. Reasons for this are that GCMs up until recently produced relatively coarse scenarios, given as monthly averages at coarse spatial and temporal resolution from which short-duration rainfall studies cannot be made. An example of a flood frequency study was that conducted by Mirza (1997) for South Asia. According to four GCM scenarios, the flood discharges in the Ganges-Brahmaputra-Meghna (GBM) basin were estimated to increase by 6-19%.

Drought frequency: Droughts are more difficult to define in quantitative terms than floods as they can imply rainfall deficits, soil moisture deficits or lack of flow in the river. Not only climatic and hydrological inputs, but also changes in water resources management, may affect drought.

Water quality: Agricultural practices may change as a result of climate change. Agricultural chemical loads in surface and groundwater may therefore change accordingly. Furthermore, higher temperatures may decrease the concentrations of oxygen and thus increase eutrophication.

Lakes: Especially closed (endorheic) lakes, with no outflow, are vulnerable to changes in climate conditions. These lakes are considered as good indicators of the effects of climate change (e.g. Aral Sea). Exorheic lakes may also be sensitive to climate change. For example, levels of Lake Victoria in East Africa have increased for several years following increases in precipitation levels.

Glaciers and ice caps: At the global scale, small valley glaciers will decline as a consequence of higher temperatures. Also, some simulations show increases in mass exchange in valley glaciers through increased winter accumulation. Especially tropical glaciers will be affected significantly by small increases in temperature.

A.7 Effects of Climate Change on Water Withdrawals

Water demand is synonymous with human and environmental ‘water requirements’. There are instream demands, these implying no withdrawals, e.g. hydropower generation, and offstream demands, which involve physical withdrawals of water. These demands can be consumptive (e.g. irrigation) or non-consumptive (water is returned to the river).

Agricultural use is the largest consumer of water in the world, currently accounting for 67% of all withdrawals and 79% of all water consumed. Municipal/domestic use accounts for 9% of withdrawals. Global water withdrawals are estimated to increase by 23-49% by 2025 over 1995 values. The greatest rates are projected for developing countries, e.g. in Africa and the Middle East, even without taking climate change into account. Water withdrawals are expected to decrease in developed countries, for example, as a result of water pricing. Industrial water currently accounts for 20% of all withdrawals. Even without climate change, these withdrawals will increase significantly, largely in Asia and Latin America.

The amount of agricultural water use is largely dependent on irrigation. Factors that influence these developments are the expansion of irrigated land, agricultural demands, water pricing and population growth. Agricultural use is relatively sensitive to climate change when compared to domestic and industrial water use. The effects on agricultural use are twofold:

- A change in field level climate which may alter the need for, and timing of, irrigation. Increased dryness may lead to increased demands, but demands could be reduced if soil moisture content rises at critical times.
- Higher CO_2 concentrations would lower plant stomatal conductance, hence increase the plant’s water use efficiency. However, this may be offset to a large extent by increased plant growth.

A.8 Impacts of Climate Change on Water Resources

Indicators of water resources stress include the amount of water available per person and the ratio of volume withdrawn to volume available. Projections show that 0.5 billion people could experience increased water resources stress by 2020 as a result of climate change. Case studies show that the impacts of different demands and operational assumptions by 2050 are greater than, or of similar magnitude to, the potential impacts of climate change.

Estimates of the cost of climate change must take into account measures used to adapt to that change, and the economic costs of climate change will depend on the adaptation strategies adopted.

It is difficult to quantitatively estimate impacts of climate change on water resources systems. Some general implications are, however, listed below:

- In systems with large reservoirs, changes in resource capacity may be proportionally smaller than changes in riverflows.
- Potential effects of climate change must be considered within the context of changes in water management. Changes in climate may have little effect on the water resources when compared to changes in water management over a period of, say, 20 years.
- The implications of climate change are likely to be the greatest in systems that currently are already highly stressed.

Also, the IPCC report urges the importance of assessing the effects of climate change in the context of the water management systems that would exist in future in the absence of climate change, considering, for example, changes in demands.

A.9 Adaptation Options and Management Implications

Most climate change studies have focused on the impacts of global warming in the absence of planned adaptation. Climate change is just one of the pressures that face a water manager. Other pressures are protection against hazards, changing water management objectives and changing technologies.

The optimum level of adaptation minimises the combined costs of adaptation and residual negative effects, with the most cost-effective steps taken first. Factors that affect adaptive capacity *per se* include institutional capacity, wealth, planning time and scale of operations.

Water management options include smart combinations of supply- and demand side approaches. Techniques for assessing alternatives include scenario analysis and risk analysis:

- *Scenario analysis* involves simulation of scenarios, which include, for example, climate change. Non-linearities in impacts and the uncertain nature of climate change may lead to the necessity of evaluating a large number of scenarios.
- *Risk analysis* involves the assessment of the risk of certain thresholds being exceeded under different possible future climates. It generally involves stochastic simulation of hydrological data.

The role of uncertainty is important in considering these alternatives and making decisions on the basis of this assessment.

Integrated Water Resources Management is regarded as the most effective way to manage water resources. It involves three components, consideration of all supply-side and demand side actions, inclusion of all stakeholders and continual monitoring and review of the water resources situation.

Two final points bear highlighting:

- Upstream adaptation may have implications for downstream users. This emphasises the need for basin-scale management.
- There is a need to look at the effects of climate change on water systems that are only managed at the household level, particularly in developing countries.

Appendix B: Abbreviations and Acronyms

A	
AOGCM	Atmosphere Ocean General Circulation Model
B	
BAHC	Biospheric Aspects of the Hydrological Cycle (IGBP)
C	
CBO	Community Based Organisation
CERUDEB	Centenary Rural Development Bank
CGIAR	Consultative Group on International Agricultural Research
CIESIN	Consortium for International Earth Science Information Network
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
D	
DWC	International Dialogue on Water and Climate
E	
EAC	East African Co-operation
ENSO	El Niño-Southern Oscillation
EPA	Environmental Protection Agency (USA)
EU	European Union
F	
FAO	United Nations Food and Agricultural Organisation
G	
GBM	Ganges-Brahmaputra-Megha Basin
GCM	Global Circulation Model
GCOS	Global Climate Observing System
GEWEX	Global Energy and Water Cycle Experiment
GHG	Greenhouse Gases
GIS	Geographic Information Systems
GRID	Global Resource Information Database
GTN-H	Global Terrestrial Observing Network-Hydrology
H	
HAPEX	Hydrological Atmosphere Pilot Experiment
HELP	Hydrology for the Environment, Life and Policy (UNESCO)
I	
IAHR	International Association of Hydraulic Engineering Research
IAHS	International Association of the Hydrological Sciences
ICZM	Integrated Coastal Zone Management
IGBP	International Geosphere Biosphere Program (ICSU)
IHDP	International Human Dimensions Program on Global Environmental Change
IHE	International Institute for Infrastructure, Hydraulic and Environmental Engineering

IIASA	International Institute for Applied System Analysis
IMAGE	Integrated Model to Assess the Greenhouse Effect
IPCC	Intergovernmental Panel on Climate Change (WMO/UNEP)
IRI	International Research Institute for Climate Prediction
IUCN	International Union for the Conservation of Nature and Natural Resources
IVM	Institute for Environmental Studies, Free University Amsterdam
IWRM	Integrated Water Resources Management

J

K

KNMI	Royal Netherlands Meteorological Institute

L

LDC	Lesser Developed Country
LOICZ	Land Ocean Interactions in the Coastal Zone (IGBP)
LUCC	Land Use and Cover Change (IGBP)

M

N

NASA	National Aeronautics and Space Administration
NHS	National Hydrological Services
NGO	Non-Governmental-Organisation
NOAA	National Oceanic and Atmospheric Administration

O

OECD	Organisation for Economic Co-operation and Development

P

PIK	Potsdam Institute for Climate Impact Research

Q

R

RCM	Regional Climate Model
RIVM	National Institute for Public Health and the Environment

S

SADC	Southern African Development Community
SAR	IPCC Second Assessment Report
SDR	Department of Rural Development (Nordeste, Brazil)
SIWI	Stockholm International Water Institute
SVAT	Soil-Vegetation-Atmosphere Transfer

T

TAR	IPCC Third Assessment Report

U

UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Program
UNESCO	United Nations Educational, Scientific & Cultural Organisation
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change

V

W

WCRP	World Climate Research Program
WHO	World Health Organisation
WHYCOS	World Hydrological Cycle Observing System (WMO)
WMO	World Meteorological Organisation
WTO	World Trade Organisation
WUE	Water Use Efficiency
WWF	World Wide Fund for Nature

X

Y

Z

Appendix C: Glossary of Terms

Useful websites with definitions of terms in the fields of Integrated Water Resources Management, climate change and stakeholder participation:

Integrated Water Resource Management (IWRM),
http://www.sce.ait.ac.th/programs/courses/iwrm/materials/glossary/glossary(F-O).htm

Stakeholder participation, World Bank website:
http://lnweb18.worldbank.org/ESSD/essdext.nsf/61DocByUnid/9FDABDCD88D03D6585256BC00065F517?Opendocument

Climate Change, UNFCCC website:
http://www.grida.no/climate/ipcc_tar/wg2/689.htm

Adaptation
Adaptation is an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects. It moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, as well as autonomous and planned adaptation:

- *Anticipatory Adaptation:* Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.
- *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.
- *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.
- *Private Adaptation:* Adaptation that is initiated and implemented by individuals, households or private companies. Private adaptation is usually in the actor's rational self-interest.
- *Public Adaptation:* Adaptation that is initiated and implemented by governments at all levels. Public adaptation is usually directed at collective needs.
- *Reactive Adaptation:* Adaptation that takes place after impacts of climate change have been observed.

Adaptive management
Diverse approaches to water allocation and management exist in the South and the North. Long evolved customary practices and long evolved 'analytical techniques for examining economic environmental policies… despite their many imperfections .. provide … valuable framework[s] for identifying essential questions that policy-makers must face when dealing with climate change. (Stakhiv 1998; IPCC 1996) There is a simultaneous adaptation 'to the exigencies of greater resource use efficiencies.. Each sector will be on a somewhat comparable 'no regrets' adaptation strategy that, collectively (i.e. via political adjustment), will beneficially affect water resources management and reduce water demands and freshwater withdrawals.

Allocative (economic) **efficiency**
This is the use of institutions, regulations and economic instruments to allocate water to activities, which bring a higher return to water.

Capacity building
This is a co-ordinated process of deliberate interventions by insiders and/or outsiders of a given society leading to skill upgrading, both general and specific, procedural improvements, and organisational strengthening. Capacity building refers to investment in people, institutions, and practices that will, together, enable countries in the region to achieve their development objective. Capacity is effectively built when these activities are sustained and enhanced with decreasing levels of donor-aid dependence accompanied by increasing levels of societal goal achievement.

Civil society
The web of associations, social norms and practices that comprise activities of a society, as separate from its state and market institutions. A healthy, powerful civil society requires institutions with strong, intellectual, material and organisational bases, reflecting social diversity. It also requires an open, constructive interaction between the civil society organisations (CSOs) and the state and market sectors. Civil society includes religious organisations, foundations, guilds, professional associations, labour unions, academic institutions, media, pressure groups and political parties.

Climate
Climate, in a narrow sense, is usually defined as the 'average weather', or more rigorously, as the state of the climate system including the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands of years. These quantities are most often surface variables such as temperature, precipitation, and wind. The conventional period is three decades, as defined by the World Meteorological Organisation (WMO).

Climate variability
Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence 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, i.e. internal variability, or to variations in natural or anthropogenic external forcing, i.e. external variability.

Climate change
Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. (IPCC, 2001).

El Niño-Southern Oscillation (ENSO)
El Niño, in its original sense, is a warmwater current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. This 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 to 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, through teleconnections, in many other parts of the world. The opposite of an El Niño event is called La Niña.

Empowerment
This is the expansion of assets and capabilities of poor people to participate in, negotiate with, influence, control, and hold accountable institutions that affect their lives. In its broadest sense, empowerment is the expansion of freedom of choice and action. It is a participatory process, which places or transfers decision-making responsibility and the resources to act into the hands of those who will benefit. This can include:

- capacity building for stakeholder organisations
- strengthening legal status of stakeholder organisations
- stakeholder authority to manage funds, hire and fire workers, supervise work, and procure materials;
- stakeholder authority to certify satisfactory completion of project and establish monitoring and evaluation indicators and
- support for new and spontaneous initiatives by stakeholders.

Forecasts
Forecasts focus on individual events where the physical processes or statistical interlinkages are relatively well understood to the extent that, depending on the nature of the event being forecast, it is possible to provide information about its timing, location and magnitude. Forecasts are thus able to reduce sources of uncertainty and hence diminish risk.

Freshwater
This includes all the easily managed water both surface and groundwater. Water which is usable in economic systems also includes soil water, which is impacted by agricultural and other types of land use.

Hazard
A hazard is a naturally occurring, or human induced, physical process or event or situation, that in particular circumstances has the potential to create damage or loss. It has a magnitude, an Intensity, a duration, has a probability of occurrence and takes place within a specified location.

Integrated water resource management (IWRM)
Integrated Water Resources Management (IWRM) is a philosophy, aprocess and a management strategy to achieve sustainable use of resources by all stakeholders at catchment, regional, national and international levels, while maintaining the characteristics and integrity of water resources at catchment scale within agreed limits. It may also be defined as a framework for planning, organising and controlling water systems to balance all relevant views and goals of the stakeholders.

Knowledge, discourse, power
Knowledge can be based on verifiable facts. Knowledge can also be constructed. The political process accepts both kinds of knowledge. Constructed knowledge is as likely to determine policy as scientifically assembled data. The contentious process of achieving a consensus which is known as 'knowledge' is achieved via discourse. Decision-makers and politicians on whom the discursive process impacts will tend to make decisions reflecting the degree of consensus achieved in a discourse. The power to change policy is available when knowledge is widely held. Knowledge is

power and it rests where the contention in the discourse places it. A politician at the centre of such contention 'only stands firm when pressed from all sides.'

Introducing 'new knowledge', for example that climate change will affect the availability of water resources, will influence water policy discourses insofar as it is cleverly constructed. Whether there are accurate predictions based on robust and precise methods is less important.

Kyoto Protocol
The Kyoto Protocol was adopted in 1997 at the Third Session of the Conference of the Parties (COP) to the *UN Framework Convention on Climate Change* (UNFCCC*)* in Kyoto, Japan. It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in Annex B of the Protocol (most OECD countries and EITs) agreed to reduce their anthropogenic GHG emissions (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) by at least 5% below 1990 levels in the commitment period 2008 to 2012. The Kyoto Protocol has yet to be enforced fully.

Mitigation
An anthropogenic intervention to reduce the *sources* or enhance the *sinks* of *greenhouse gases* (IPCC, 2001). However, within the disaster management community, mitigation is differently defined (see *risk mitigation*).

No regret principle
No regret measures are those whose benefits equal or exceed their cost to society. They are sometimes knows as 'measures worth doing anyway'.

North and South
North: Northern economies are generally industrialised and have developed comprehensive public sector institutions capable of enabling and controlling their productive private sectors. Engines of both change (e.g. government) and development (e.g. the markets) are diverse and strong. Northern political economies are rich in social adaptive capacity.

South: Southern political economies are characterised by non-diverse weak economies and generally poor social adaptive capacity.

Participation
This is a process through which stakeholders influence and share control over development initiatives and the decisions and resources, which affect them. It is a process, which can improve the quality, effectiveness and sustainability of projects and strengthen ownership and commitment of government and stakeholders.

Politics
Politics explains 'who gets what, when and how.' (Allan, pers. com.)

Precautionary principle
The precautionary principle recognises that the absence of full scientific certainty shall not be used as a reason to postpone decisions when faced with the threat of serious or irreversible harm.

Predictions
Predictions are based on statistical theory, which uses the historical records to estimate the probability of occurrence of events. Predictions are therefore based on average probabilities and give no indication of when a particular event may occur.

Preparedness
Preparedness includes those pre-arranged emergency measures, which are taken to minimise the loss of life and property damage following the onset of a hazard.

Productive (technical) **efficiency**
This is the use of technical measures to increase the returns to water. These technical measures include dams, canals, drip irrigation, and water treatment.

Resilience
A resilient socio-ecological system is synonymous with a region that is ecologically, economically, and socially sustainable. Because the word 'resilience' has been used in different ways, we need to be clear about its meaning. One interpretation has to do with the rate of return of a system to some equilibrium state after a small disturbance. This is what we term 'engineering resilience'. The Resilience Aliance (2001) define resilience as the magnitude of disturbance that can be experienced before a system moves into a different state and different set of controls – 'ecosystem resilience', as originally conceived by Holling (1973). Based on this interpretation, resilience is defined as follows: 'Resilience' as applied to ecosystems, or to integrated systems of people and natural resources, has three defining characteristics:

- The amount of change the system can undergo and still retain the same controls on function and structure (still be in the same state - within the same domain of attraction)
- The degree to which the system is capable of self-organisation
- The ability to build and increase the capacity for learning and adaptation

Risk
Risk is a quantitative measure of a defined hazard, which combines the probability or frequency of occurrence of the damaging event (i.e. the hazard) and the magnitude of the consequences (i.e. expected losses) of the occurrence

Risk mitigation
Risk mitigation considers setting up alternative measures to reduce the impacts of a hazard by minimising its destructive and disruptive effects, thereby lessing the scale of the disaster. It attempts to find practical and workable strategies and solutions for minimising risk at scales ranging from international, to national to local.

Sanctioned discourse
A sanctioned discourse occurs where a very long evolved fundamental idea is embedded in a discourse. Where a large population has experienced millennia of adequate water availability it is extremely difficult to contradict that communal sense of security. Politicians are unwilling to pay the political price of communicating the bad news. The discourse is sanctioned by the mutual need to hold on to the essential lie.

Scenario
This is defined as a plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a 'narrative storyline'.

Sensitivity
Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. Climate-related stimuli encompass all the elements of climate change, including mean climate variability, and the frequency and magnitude of extremes. The effect may be direct or indirect.

Social adaptive capacity
The scarcity of the social resources of adaptive capacity is more important than the scarcity of water. The ameliorative measures enabled by social adaptive capacity can always solve a water shortage. Abundant freshwater does not determine the development of a strong and diverse economy.

Stakeholders
These include all individuals and/or groups who are affected by, or can affect, a given operation. Stakeholders can be individuals, interest groups, corporate organisations

Sustainability
The achievement of 'sustainable' water allocation outcomes is a political process. Sustainability has three dimensions:

- The necessity for a political economy in order to have social sustainable society;
- a sustainable economy;
- as well as, a sustainable water environment.

The water environment provides the underpinning environmental services that enable the other two dimensions of sustainability.

Vulnerability
Vulnerability is the degree to which a system is susceptible to, or 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 as well as the variation to which a system is exposed, including its sensitivity and its adaptive capacity (IPCC, 2001).

Vulnerability may also be defined as the characteristic of a person, or group, or component, of a natural system in terms of its capacity to resist and/or recover from and/or anticipate and/or cope with, the impacts of an adverse event (Downing et al., 1999)

Water scarcity
This occurs when a community's demands for freshwater for social, economic and environmental functions exceed the available water supply. Water scarcity is ameliorated by improving productive (technical) and allocative (economic) efficiency and by accessing water outside the catchment or the political economy. Water can be conveyed by pipeline or by vessel, can be accessed as virtual water and it can be desalinated. The first order *scarcity of water* is much less important than the second order *scarcity of social adaptive capacity* to ameliorate the physical water scarcity (Allan, 2001).

Weather
Weather is the sum total of prevailing atmospheric variables at a given place and at any instant or brief period of time. Weather is an everyday experience – one talks of ' today's weather'

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