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# Africa's Water Resources in a Changing Climate

*Toward an Operational Perspective*

## Summary Report



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## Executive Summary

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***Africa faces many development challenges.*** As Africa enters the new century, important investments are planned or underway to meet the substantial development challenges in the Region. These include the provision of basic services in health, education, water supply, sanitation, agriculture, and mobility, as well as larger, growth-oriented investments in power, dams, transport, ports, and urban development.

***Water resources are critical to Africa's development.*** Many of the activities underway or planned to spur economic growth and alleviate poverty in Africa are related to water in one way or another. For example, underdevelopment of the continent's water storage infrastructure increases the risks posed by floods and droughts while reducing the productive potential of rivers. The region has tremendous untapped hydropower potential. There is substantial scope for improving agricultural water management to support the region's extensive rainfed agriculture and expanding irrigation. The region's rural and urban water supply needs can be met with targeted investments in surface and ground water supply and quality management. Coastal areas and islands bear the brunt of coastal storms, erosion, land subsidence, and the intrusion of salt water into valuable aquifers. Water-related diseases exact a heavy toll on the people of Sub-Saharan Africa. Degrading watersheds require improved land and water management to conserve moisture, reduce erosion, and improve productivity. Improved basin planning and management are essential to optimize the sustainable use of resources and better manage intersectoral and interregional conflicts.

***Managing the region's water has always been difficult and susceptible to the uncertainties of climate variability.*** Managing water resources in an optimal and sustainable manner across sectors and regions is already a challenge. In addition, most of the region's water lies in transboundary river basins, posing additional political and institutional challenges to investment planning and resource management. Moreover, the region encompasses a wide variety of climatic zones, from the Sahara desert to the rainforests of the Congo basin. The economies of the region are very susceptible to climate variability—from season to season and from year to year. Droughts, floods, and storms undermine the region's progress.

***Climate change threatens to exacerbate the uncertainty of planning for the future.*** The scientific consensus that world temperatures will rise poses significant concerns—among them increased evaporation and losses from water-management systems, increased crop water requirements, and decreased productivity of sensitive agricultural systems. Those changes may be offset or aggravated by changes in precipitation over Africa, and on this point there is little consensus among climate models. There is even less consensus on the impact of climate change on climate variability, coastal storms, or the El Niño–Southern Oscillation effects that influence the climate in many parts of Africa.

***Much of the discussion on climate change is governed by emotion, generalities, or narrow scientific discourse. Policy makers, planners, and development professionals need more structured approaches on how to operationalize what is known (and not known) about climate risks.*** Intermediation between scientists, governments, development partners, and the general public is critical not only for retrofitting existing investments and planning new investments, but also for managing water systems in a manner that is fully sensitive to variations and long-term trends in climate.

***In the face of uncertainty, how should countries incorporate existing and evolving climate risks into their water planning?*** How can they ensure that their decisions are flexibly responsive to future climate scenarios? How do they undertake the goal of “climate-smart development” — that is, development that takes into account both historical climate variability and likely future climate change? Addressing these questions requires a comprehensive assessment of climate risks in the context of existing and proposed investments. That assessment must synthesize all available information to guide those involved with water-related investments and management. Traditional approaches have not been sufficiently comprehensive or meaningful, and also often do not do justice to known historical climate variability. They often involve picking a few (sometimes one) climate model outputs (sometimes downscaled) of a few future scenarios, examining the implication for system hydrology, and discussing their implications.

***This report proposes and applies an alternative analytical framework for assessing climate risks*** that integrates more information to permit better water-planning decisions. The methodology sets performance indicators for selected systems, determines their sensitivity to development, and integrates historical data on climate variability, as well as climate change projections about which there is general consensus. Unlike most approaches to date, the methodology does not embrace one or only a few of several equally likely climate models where those models generate results that vary widely (as is the case with precipitation projections). The results of ongoing work on the Niger Basin in applying this framework are highlighted.

***The key findings include:***

- It is important to consider climate risks in a holistic manner (including both historical variability and climate change) and in the context of other evolving changes (e.g. population, economic growth, demand for water services, etc.) in a river basin context.
- It is critical to improve ready access to climate information and find ways to improve their visualization and use in water planning. Such tools have been developed as part of this work and are being integrated into the World Bank Climate Portal and can help to improve the consideration of climate risks in water resources planning and management.
- Adaptation to climate change needs to be based on a systematic analysis of climate risks and adaptation options.
- Existing knowledge base and modeling tools for river basin planning can be used to analyze the vulnerability of key water resource system performance indicators to

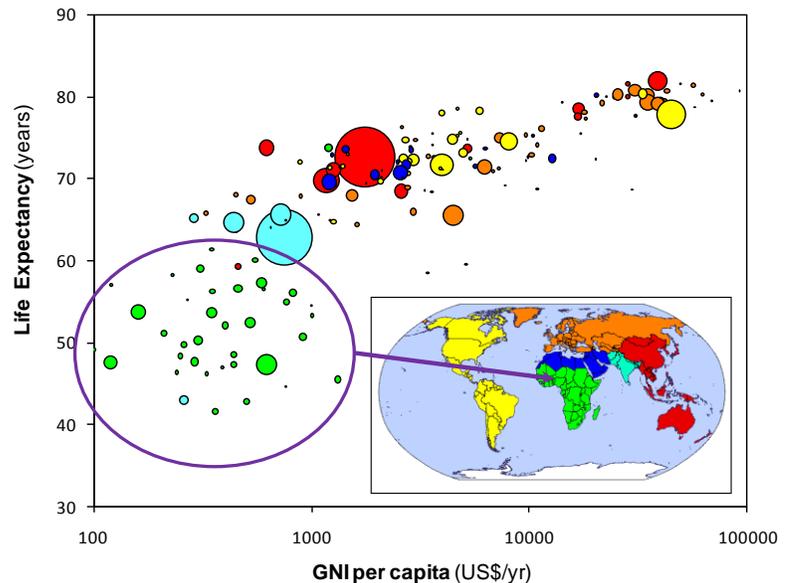
climate risks (manifested as variations in key hydrologic cycle variables as a result of historical climate variability and the suite of the best available climate change scenarios) in order to better plan adaptation measures.

- A best first step in adapting to future climate change in the water sector is to adapt to existing climate risks. Before looking ahead at climate change alone, it is important to look back at historical climate variability. For example, Africa has yet to come close to coping adequately with historical climate variability.

## Chapter 1: Context

- Meeting Africa's substantial development needs will depend in great part on the sustainable use and management of the region's water resources.
- Africa's water resources are vulnerable to climate risks and threatened by climate change.
- Improved adaptation to climate risks in water resources planning and management is essential for Africa's development.
- A robust and flexible climate-risk assessment methodology is needed to guide water-related investments.

**Africa is the least-developed region in the world.** About 40 percent of the world's poor live in Sub-Saharan Africa. Half of the region's population lives in absolute poverty, and almost a fifth suffers from chronic hunger. The region contains 22 of the 24 countries in the lowest category of the United Nations' Human Development Index (HDI). The average life of an African is 47 years, and about 10 percent of children do not make it to their fifth birthday, accounting for half the global child mortality. Africa accounts for most of the 500 million cases of malaria every year and for 90 percent of the 1 million fatalities. Figure 1.1 shows the clustering of African nations in a global comparison of life expectancy and per capita incomes.



**Figure 1.1 Africa lags in socioeconomic development**

Note: bubbles represent countries sized by population

Many of the region's countries face complex issues of conflict, corruption, and governance that undermine economic growth and poverty reduction. The GDP per capita is about \$200, compared with the global average of \$2,000. Africa is not expected to meet many of the Millennium Development Goals by 2015. It remains the only region in which per capita food production and income have declined in recent decades. Africa's share of the world's people who earn less than a dollar a day increased from 11 percent in 1970 to more than 33 percent in three decades. At current trends, the region is projected to account for more than two-thirds of the world's poor by 2015.

**Water illustrates the contradiction of Africa's poor development status and its rich natural resources.** Although Sub-Saharan Africa generally has abundant water, it also has the lowest water supply of any region. Only 62 percent of the population has access to safe water, against a global average of 80 percent, and only a third of the population has adequate sanitation facilities. The average African consumes less than 20 liters a day per person, compared with 150 liters in the United Kingdom and 600 liters in the United States.

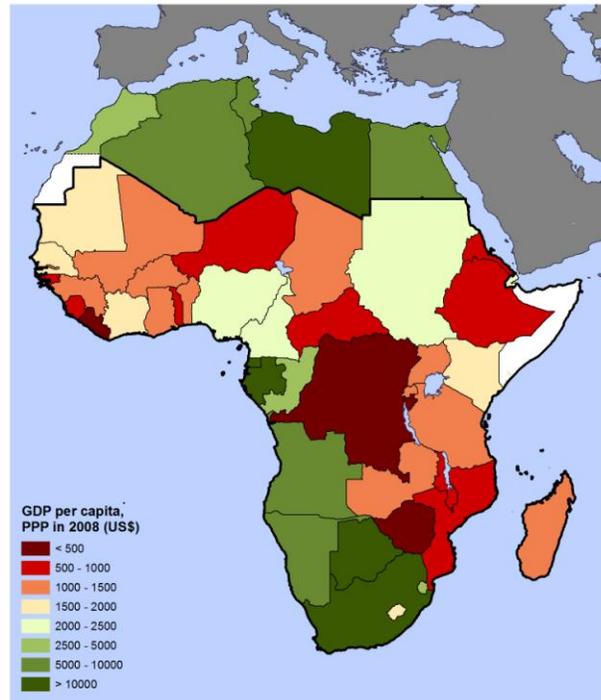
Despite high hydropower potential, the region has very poor access to electricity, and about 80 percent of the region's population depends on burning biomass for energy, enhancing deforestation and watershed degradation. While electricity use worldwide averages about 2,500 kwh/capita (more than 10,000 kwh/capita in most developed economies), Africa has the lowest electricity consumption in the world at about 500 kwh/capita/year. Thirty-two African countries consume less than half that amount (e.g., Ethiopia consumes only about 40 kwh/capita/yr). About 550 million Africans do not have any access to electricity. In many countries, such as Mozambique, Malawi, and Uganda, less than 10 percent of the population has access.

GDP per capita is low at about a tenth of the global average (see figure 1.2). About 97% of Africa's agricultural areas are rainfed (FAO 2002). With Africa's agricultural productivity the lowest in the world, food security is threatened by poor development of irrigation systems and the high vulnerability of rainfed agriculture to highly variable and changing weather patterns. While a third of Africa's population lives in drought-prone areas, in many countries floods take a devastating toll in lives, livelihoods, and property damage.

***Transformational change will require significant additional investments to accelerate growth and reduce poverty.***

Africa's GDP per capita has grown 54 percent in the first decade of the new millennium, compared with 15 percent in the previous decade. Agricultural GDP has grown by 4% per year and poverty has also declined by 1% per year in the last decade. Many African countries have established themselves on the path to strong economic growth and far exceed the average statistics for the region. But breaking free from the poverty trap that many African countries face will require substantial investments to provide basic services and fuel sustainable economic growth. Many countries have identified and are undertaking priority investments in a number of sectors. These include investments in education, health, water supply and sanitation, power generation and transmission, water storage, agricultural systems, irrigation, transport, urban development, and rural services. But the cost of closing Africa's "infrastructure gap" could reach \$93 billion annually, about half in the power sector (World Bank 2010a). Substantial investments needed for education, health, and several other sectors would add much more to that already imposing sum.

***Many of the investments that Africa must make involve water resources.*** Africa's substantial water resources will need to be sustainably developed to provide the water supply, hydropower, agricultural water, and environmental services required for the development of the countries of the region.



**Figure 1.2 Per capita GDP is very low in Africa**  
 Source: based on World Development Indicators (The World Bank)

- Investments in hydro-meteorological systems are critical to improve water resources planning, investment preparation, and disaster management.
- Water supply is an essential service for rural areas and for rapidly growing and industrializing cities.
- Hydropower is proposed to account for about half of the 7,000 MW/year of installed capacity that Africa now requires.
- Appropriate water storage at all levels (from small check dams used for watershed management to large dams for hydropower) must be developed to improve hydrologic regulation for improving flood management, low flow augmentation, environmental services, and water productivity.
- Substantial investments are required to increase Africa's low current level of irrigation.
- As Africa urbanizes and industrializes, additional investments in pollution management will be needed to maintain the sustainability of the surface and groundwater resources.

***Climate variability has a significant impact on water-related development.*** Africa is characterized by great variability in climate, both spatially (across the region) and temporally (from season to season and from year to year). That variability affects growth and livelihoods:

- Droughts and floods severely affect water supply and agriculture. In 2002, about 14 million Ethiopians faced drought. In 1983, 300,000 Ethiopians perished because of prolonged drought, leading to the 1984 "Live Aid" efforts.
- Water flow variability can reduce hydropower generation. The Volta River droughts of 1982–84 and 1994 resulted in severe drops in hydropower production in the Akosombo and Kpong plants causing severe power cuts to consumers and industries.
- Floods cause terrible devastation, uprooting millions, killing livestock, ruining crops, and destroying homes and infrastructure. Even though they have claimed fewer lives than drought (the worst in Africa in recent years being the 1997 Somalia floods that killed about 2,300 people), floods can be quite deadly in combination with other disasters. Mozambique is still recovering from the floods of 2000 (that reduced its GDP by 1.5%), which were followed by a cyclone.

In view of the high degree of climate variability it currently faces, the region has insufficient capacity to plan for and manage water shortage and excess.

***Climate change compounds the threat posed by variability.*** Climate change is expected to exacerbate Africa's coping deficit. There is general scientific consensus that greenhouse gas (GHG) emissions, primarily from human activity, are changing the world's climate. In cooler parts of the world, the projected effects of those changes are not all bad. But there is little upside to projected temperature increases in Africa. Water requirements for rainfed and irrigated crops, evaporation, and other water losses are all expected to increase, placing stress on water systems. The rising sea level threatens coastal areas, makes storm surges more devastating, and endangers coastal and island lands, aquifers, and ecosystems. The little snow and ice found on the continent is also projected to shrink substantially. Precipitation scenarios indicated by several climate models are of great concern.

***Africa still has a long way to go in coping with historical climate variability.*** Historic climate variability has always played a significant role in designing investments in sectors affected in one way or another by the weather. In fact, many water investments (dams, irrigation, diversions) are made precisely because the climate varies spatially and temporally, resulting in supply-

demand mismatches. The planning of water-related investments in storage, hydropower, irrigation, and bulk water supply have always been subject to climatic and hydrologic uncertainties, and increasingly sophisticated methodologies are used to weigh the risks against the benefits of various designs. Hydro-climatological uncertainty is one of the many factors that influence the economic viability of water investments, which may be undermined by increased variability and temperature stresses or enhanced by the climate-adaptation measures that societies take to improve their climate resilience. Improving the poor hydro-meteorological systems in Africa is a critical priority to enhance this coping.

***Climate change is not the only determinant in water planning.*** Water-related investments have always been planned to deliver livelihood and economic growth benefits to growing populations. In the future, population increase, economic growth, and increasing urbanization and industrialization will continue to be key determinants of water-related investments. In Africa, the same pressures are stimulating water investments to close historical “*development deficits*.” Those investments are stressing water resources, especially in already stressed areas, through over pumping of groundwater from coastal aquifers, increased competition for water (in the Nile, for example), and pollution of surface water and groundwater. The uncertainties implicit in current development trends—demographic, technological, and economic—will no doubt continue to shape the choice and design of water-related investments. As the World Bank Africa Region’s recent strategy (World Bank 2011) indicates, any strategy for Africa should also take into account the differences among countries in levels of development (per capita incomes range from \$200 in Burundi to \$20,000 in Equatorial Guinea), economic structure, and political and social environment. Climate risks (both historical variability and climate change) must be considered in this complex calculus. The World Development Report in 2010 (World Bank 2010b) urges countries to “act now, act differently, and act together” to address climate challenges.

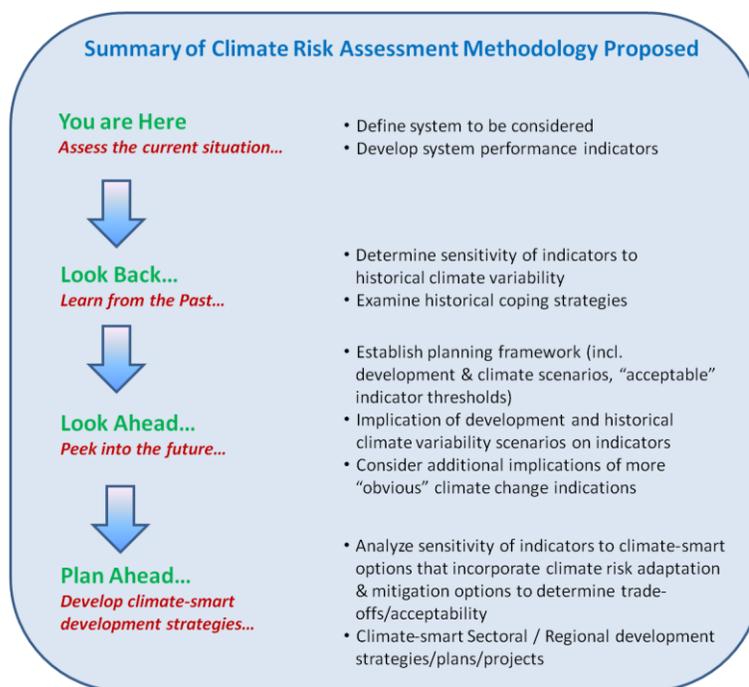
***There is a need to operationalize the discussion of climate risks—with a strong focus on historical climate variability.*** While the mitigation story is increasingly clear, the debate on adapting to climate change is not usually based on a systematic analysis of climate risks and adaptation options.. Each new natural disaster is sometimes looked on as proof of climate change, even if the historical record reveals the event to be routine or relatively minor. Attempts are made to distinguish between adaptation investments that are required for coping with the existing (or historical) climate variability and the additional adaptation investments required to manage climate change concerns. The distinction is largely artificial. Most lists of climate-change adaptations (information, institutions, and investments) look no different from lists of measures needed to cope with the region’s development deficit and adapt to the historical variability in its climate (with the exception of coping with sea level rise). For example, should hydro-meteorological and flood-forecasting systems be improved to parry the risk of additional climate variability predicted by some climate change scenarios or should they be improved anyway to better cope with existing climate problems? To pose the question is to answer it. But how, then, should one use the results of billions of dollars of climate change research in a practical and operational manner? How, in light of that research, should we change the way we design or operate a particular dam? How should we factor in future climate risks when designing agricultural water management systems, planning hydropower facilities, or planning investments in river basins (as in the case of the Niger basin, where the nine riparian countries have agreed on a coordinated investment plan)?

**Current approaches in climate change assessment are often inadequate and misleading.**

Climate models are not consistent in their projections for precipitation (and consequently runoff) in Africa, especially at the subregional level which is the level that is critical to planning water investments. The lack of consistency in the projections of various climate models and scenarios, all “equally likely”, makes it extremely difficult to use them to plan and implement adaptation strategies. Almost all studies on climate change implications have chosen a few climate-model outputs (sometimes based on how well they represent the past) and used them to specify ranges for various hydrologic parameters on various spatial and temporal scales. Those outputs are sometimes further refined with statistical and dynamical downscaling (sometimes based on a single GCM) to determine projections for temperature, precipitation, runoff, and other hydrological parameters that are then used in additional impact analyses with even more socioeconomic and development assumptions. The results give deceptively definitive accounts of the future of hydropower systems, irrigation systems and water deficits, and other phenomena. Although such analysis may provide some general insights, due to the large uncertainties in the results, this type of analysis cannot be confidently used to design climate change adaptation strategies.

**A robust and flexible climate-risk assessment methodology is needed to guide water-related investments.** We need to integrate climate risks more systematically into the plans we make to develop, operate, and manage water resources. In such planning, there is substantial room to increase our consideration of existing (historic) climate variability. Wherever possible, investments should be analyzed as part of a system (for example, as part of a basin) rather than project-by-project, and a planning framework should be developed with the definition of appropriate system-performance indicators at its core. Within such a framework, a range of development and climate scenarios could be examined and assessed based on their implications for these indicators. The goal would be to test the responsiveness (or robustness) of investment plans and operational decisions to climate risks.

This report proposes a simplified methodology to better integrate climate risks into investment planning and operations. An outline of the plan is presented in figure 1.3; details are found in chapter 6. The first step in the methodology is to identify the system being considered (a basin, subbasin, dam project, or irrigation scheme, for example) and to choose performance indicators for that system that are important to system stakeholders (such as hydropower generation or rice production). The next step is to examine the hydroclimatological



**Figure 1.3 Summary framework for climate-smart development planning**

record to gauge the sensitivity of the system indicators to the past events in the record. Turning

next to the future, the methodology weighs the impacts of various scenarios on the same indicators. The scenarios include those related to development efforts as defined in sector plans (for example, additional irrigation, hydropower generation, and water storage) as well as those related to climate, as suggested by the historical record and climate-change models—at least in those areas where the models tend to agree (for example, on temperature increases, rise in sea levels, and, possibly, precipitation levels). The methodology then proposes synthesizing climate adaptation and mitigation options into “climate-smart” development strategies and plans. Additional analysis of such options will be needed to determine how to match system indicators to planning thresholds, with identification of trade-offs.

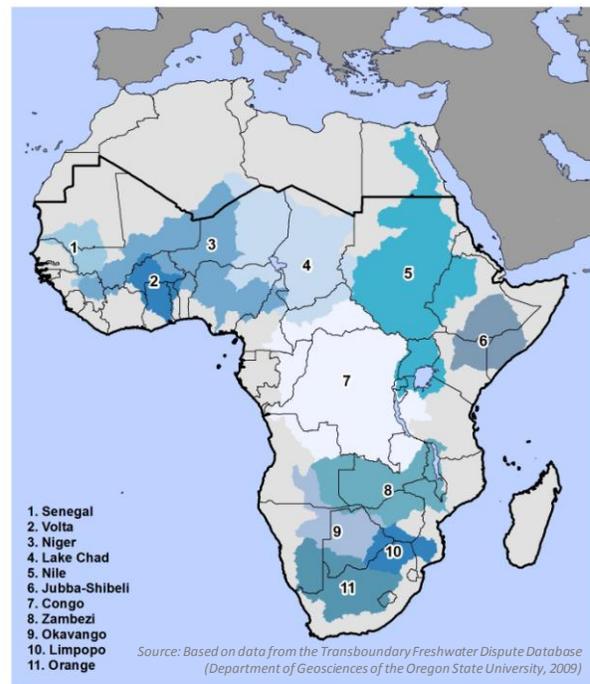
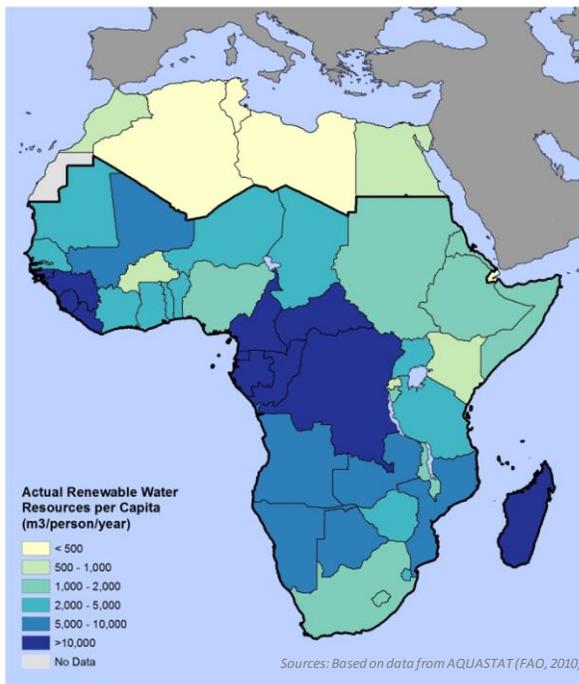
Many of the adaptation options that emerge from applications of the methodology will appear familiar. They will tend to be of the type that would have been good things to do regardless of the results of climate-change models or of the detailed examination of climate records. The essential distinction is not that the options will tell us to do different things but that they may tell us do things differently—with more flexibility in design and operations to better manage uncertainty. In short, the methodology and its outputs will help us engage in “adaptive adaptation.”

***This report looks at water resources development through a climate lens.*** It summarizes efforts undertaken by a large, multidisciplinary team of experts within and outside the World Bank. The second chapter provides a quick overview of Africa’s water resources. The next two chapters focus respectively on historical climate variability in Africa and projected climate change. In chapter 5, the focus shifts to the development implications of evolving climate risks. Chapter 6 proposes a systematic way to undertake climate risk assessments. The last chapter applies these concepts to climate-smart development. The project that produced this report has also developed other products (including interactive tools) that will be integrated into the World Bank’s evolving climate portal and other projects, programs, and studies in the Bank’s Africa Region.

## Chapter 2: Africa's Water Resources

- Africa's substantial water resources are underutilized.
- The continent's development prospects depend heavily on the sustainable development and management of water resources.

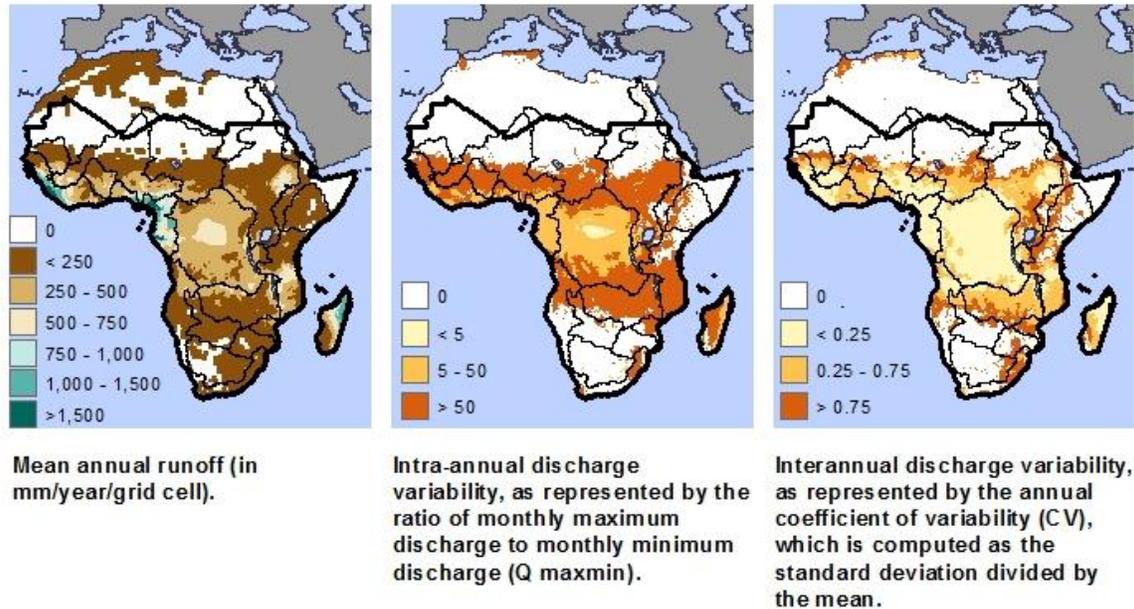
**Africa is endowed with substantial water resources.** Africa encompasses a wide variety of hydrologic settings, and several of its countries have substantial water resources (figure 2.1). Seventeen rivers have catchment areas greater than 100,000 km<sup>2</sup> (see the major basins in figure 2.2). Some of these rank among the great river systems in the world. For example, the Congo, with an annual flow of about 1,300 billion m<sup>3</sup>, is second only to the mighty Amazon. The Congo's flow is greater than all the other major rivers of Africa combined. With a length of 6,650 km, the Nile has long been recognized as the longest river in the world. However, only fifteen percent of precipitation is converted to runoff in Africa, the lowest level of any region in the world. The continent has more than 160 lakes larger than 27 km<sup>2</sup>, most of which are located near the equator or in the sub-humid East African highlands of the Rift Valley. Few groundwater assessments are available, but total storage is estimated to represent 15 percent of the continent's water resources, with the major aquifers located in arid zones of the northern Sahara, Nubia, Sahel, and Chad basins, and in the Kalahari.



**Figure 2.1** Many of Africa's countries have substantial water resources

**Figure 2.2** Major river basins of Africa

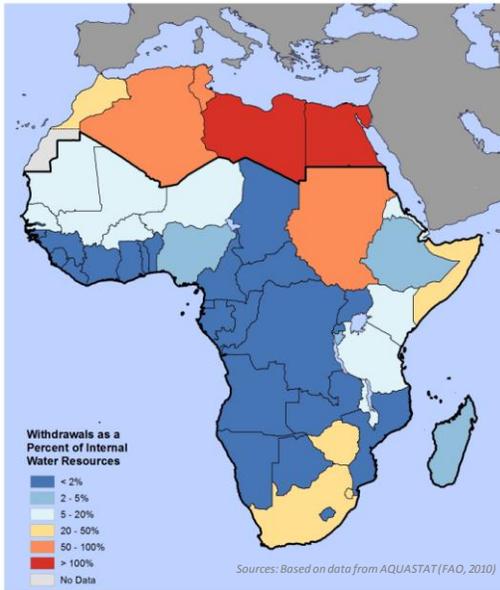
**Hydrologic variability is very high.** Hydrological variability and extremes are at the heart of the challenge of achieving basic water security in Africa. Figure 2.3 illustrates the large intra- and inter-annual variability, as well as spatial variation in river flows in African basins. The historical climate variability is examined in detail in the next chapter.



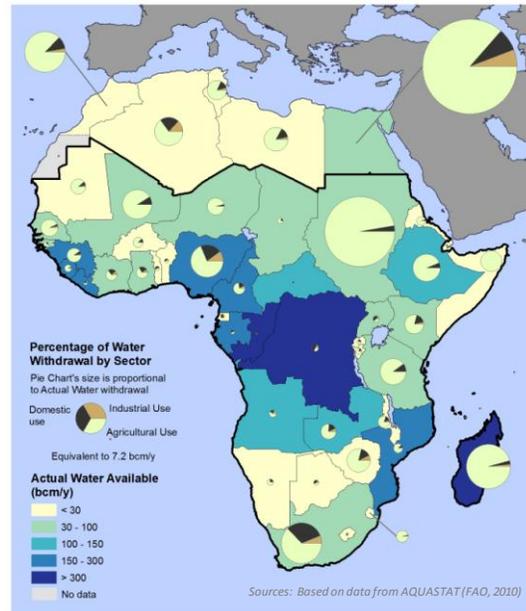
**Figure 2.3 Spatial and temporal hydrologic variability in Africa (1960-1995)**

Source: Vörösmarty et al., 2005.

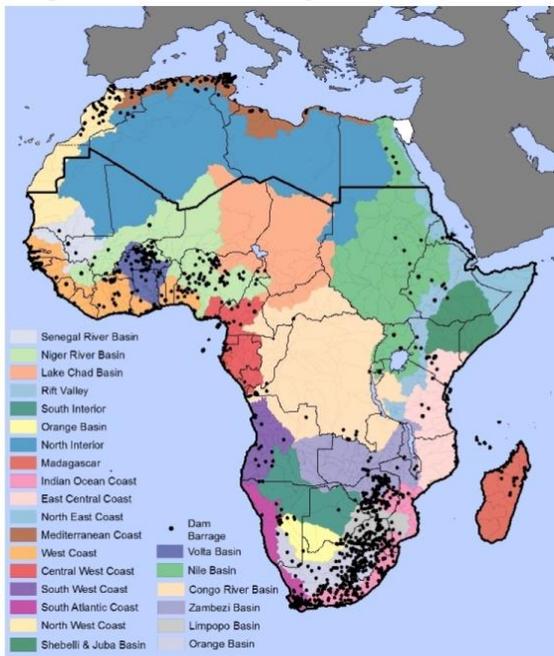
**Africa uses very little of its significant water resources.** Except in some parts of southern Africa and parts of the Nile basin, water availability is not a constraint to development (figure 2.4). For example, less than two percent of the Congo's tremendous water resources are used. Africa has about nine percent of the globe's freshwater resources, but utilization is low in many basins. Most water use in the continent is for agriculture (figure 2.5), although domestic and industrial uses of water are growing near urban areas.



**Figure 2.4** Current water withdrawals are low (compared to the availability).

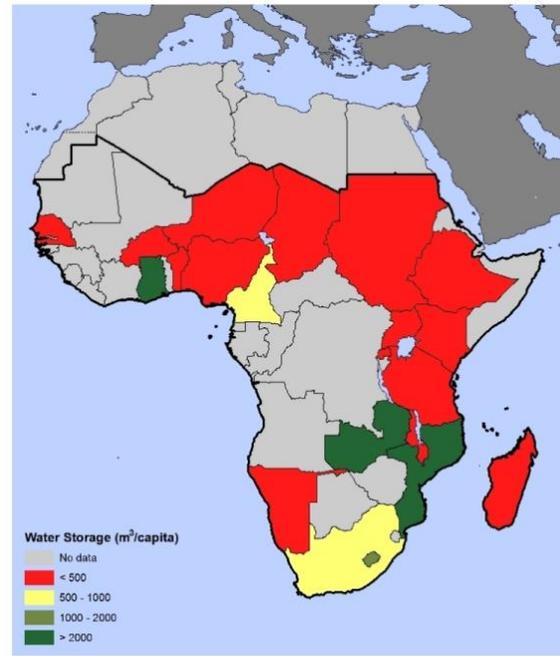


**Figure 2.5** Most water is used for agriculture



**Figure 2.6** Africa has developed little water storage

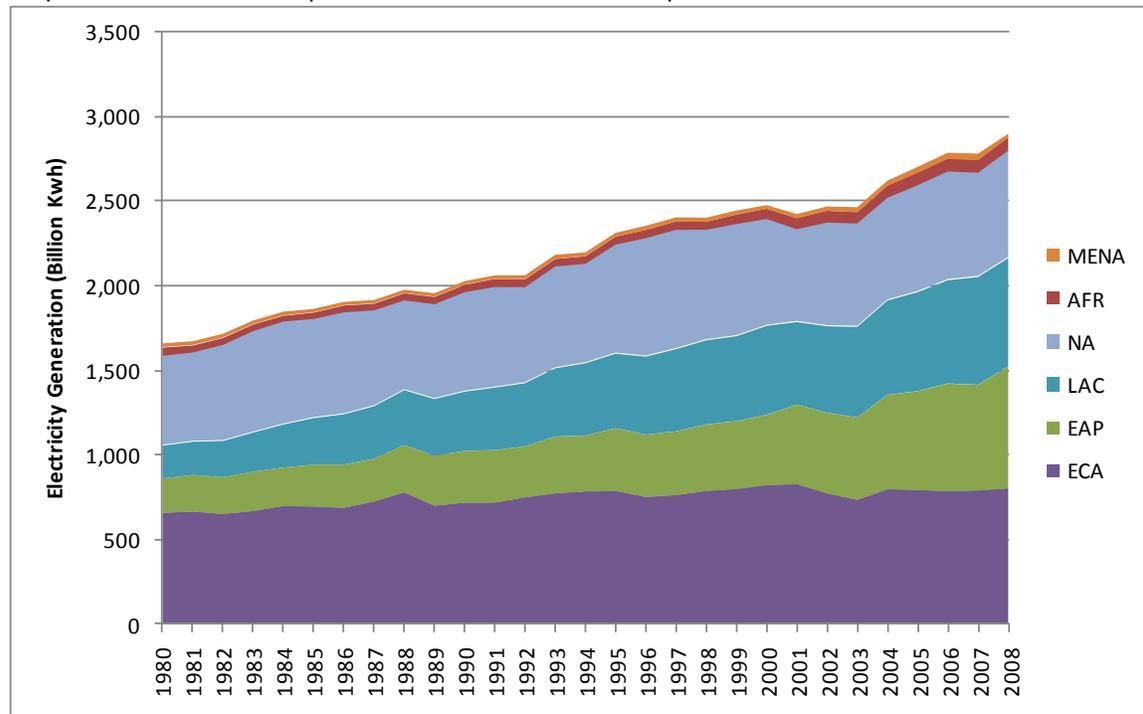
Source: Based on data from FAO & World Bank



**Figure 2.7** Water storage per capita is low

**Water storage infrastructure and hydropower are underdeveloped in Sub-Saharan Africa.** In Sub-Saharan Africa, there is not enough water storage infrastructure (including both small check-dams and larger multipurpose storage systems) to compensate for hydrological variation in almost all areas. Storage capacity in Africa averages about 200 m<sup>3</sup>/person/year (see figures 2.6 and 2.7), compared to 5,961 m<sup>3</sup>/person/year in North America. Existing storage infrastructure is inadequate to reduce flood peaks and augment low-season flows in highly variable river systems.

The development of hydropower in Africa lags far behind other world regions (figure 2.8), despite its substantial scope and even more substantial potential.



**Figure 2.8 Africa has developed little of its hydropower potential**

Data Source: IEA website

Note: MENA: Middle East and North Africa; AFR: Sub-Saharan Africa; NA: North America; LAC: Latin America and the Caribbean; EAP: East Asia and Pacific; and ECA: Europe and Central Asia

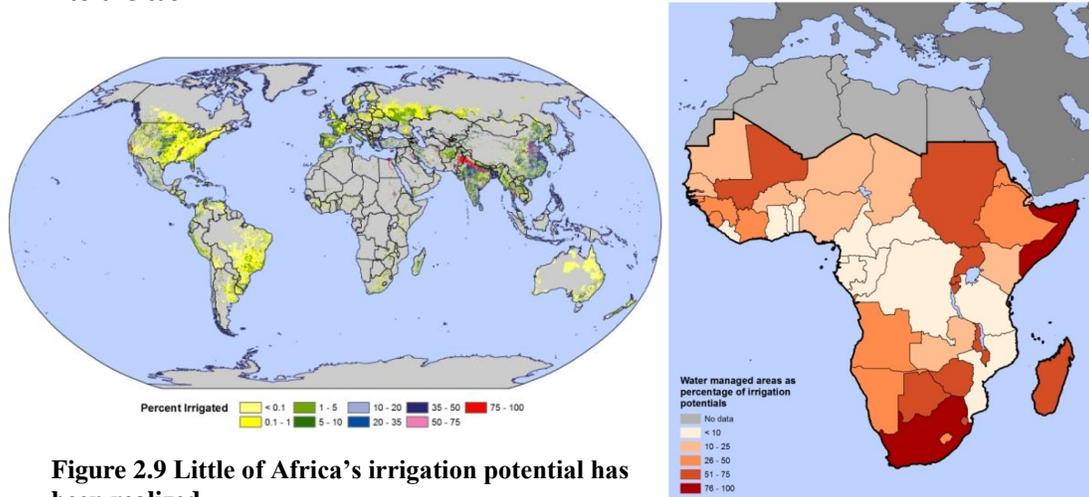
**Water is central to Africa's development prospects, just as it has been the source of many of its past woes.** It is clear that additional investments in water resources will be needed if Africa is to meet its needs for economical electric power; reliable supplies of water for irrigated agriculture, household consumption, and sanitation; and flood and flow control (to protect agriculture, settlements, and terrestrial and aquatic environments). It is equally clear that inadequate development and poor management of water have contributed to the droughts and floods that have devastated livelihoods, sparked resource-based conflicts, and undermined growth in Sub-Saharan Africa.

Undoubtedly, there are many other factors that cause, and are often aggravated by, widespread poverty—among them low access to basic services, poor governance, and underdevelopment of the private sector. Many of these related factors have their roots in the way in which water resources have been developed or managed. For example, when access to water is limited,

health and hygiene are compromised and there are and substantial opportunity costs of lost time.. Low access to and consumption of power in Africa reflects the underdevelopment of the region's hydropower potential. Roads are often damaged by floods and unchecked erosion. Water-borne or -related diseases such as malaria, diarrhea, and river blindness (schistosomiasis) take a heavy toll on Africa's population. Poor access to reliable water and vulnerability to droughts and floods limits incomes, trapping millions in poverty.

**The productive potential of the water is significant.** Water infrastructure in Africa is poorly developed, owing to weak institutions, inadequate capacity, and limited financing. The existing infrastructure performs poorly for similar reasons. If properly developed and exploited, however, the region's water resources could provide substantial productive benefits for food, people, energy and the environment as described below:

- **Water for food.** African economies are still largely dependent on rainfed agriculture, leaving people vulnerable to climate risks. In Ethiopia vulnerable populations engage in subsistence agriculture under difficult and highly variable rainfall conditions on more than 10 million hectares, while only about 200,000 hectares are irrigated. The map of global irrigation in figure 2.9 (released by the UN Food and Agricultural Organization in 2007) reveals how little of Africa is irrigated in comparison with the rest of the world. In many African countries, water for food is limited by a combination of natural factors (such as terrain, soils, and land degradation), poor water-regulation infrastructure, poor access to markets, land tenure, and other services. Yet in large parts of the continent one finds substantial fertile land and significant water resources that could revolutionize global food production if adequate investments and good institutions could be applied to the task.



**Figure 2.9 Little of Africa's irrigation potential has been realized.**

Source: FAO

Population growth has contributed to increasing food insecurity in the region. Irrigated agriculture offers the solution—it has the potential to meet the estimated 3.3 percent increase in agricultural output required to achieve the continent's objectives of food security.

- **Water for energy.** Just 7 percent of Africa’s hydropower potential—estimated at 1.4 million GWh/year—has been harnessed, compared with 75 percent of Europe’s hydropower potential, 69 percent of North America’s, 33 percent of South America’s, and 22 percent of Asia’s. Similarly, access to electricity in most African countries is less than 200 kWh/person/year and, in some countries, less than 30 kWh/person/year. In comparison, access to electricity in North America is more than 12,000 kWh/person/year. South Africa alone consumes about two-thirds (210 billion kwh in 2005) of Sub-Saharan Africa’s electricity consumption (310 billion kwh). Substantial hydropower resources are available for sustainable development in the Democratic Republic of Congo and in the Ethiopian highlands (figure 2.10), but investment lags far behind potential—clearly a missed opportunity.

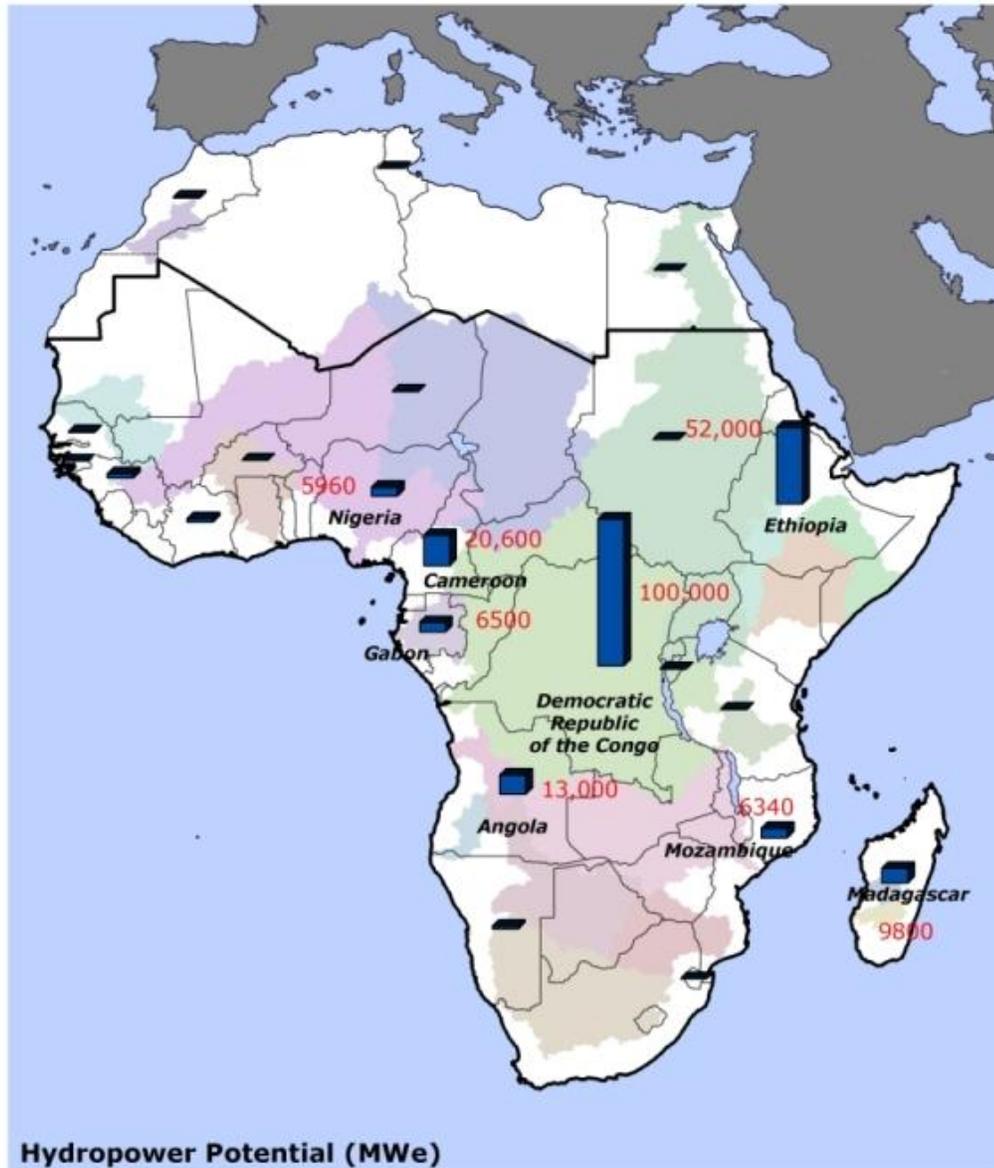
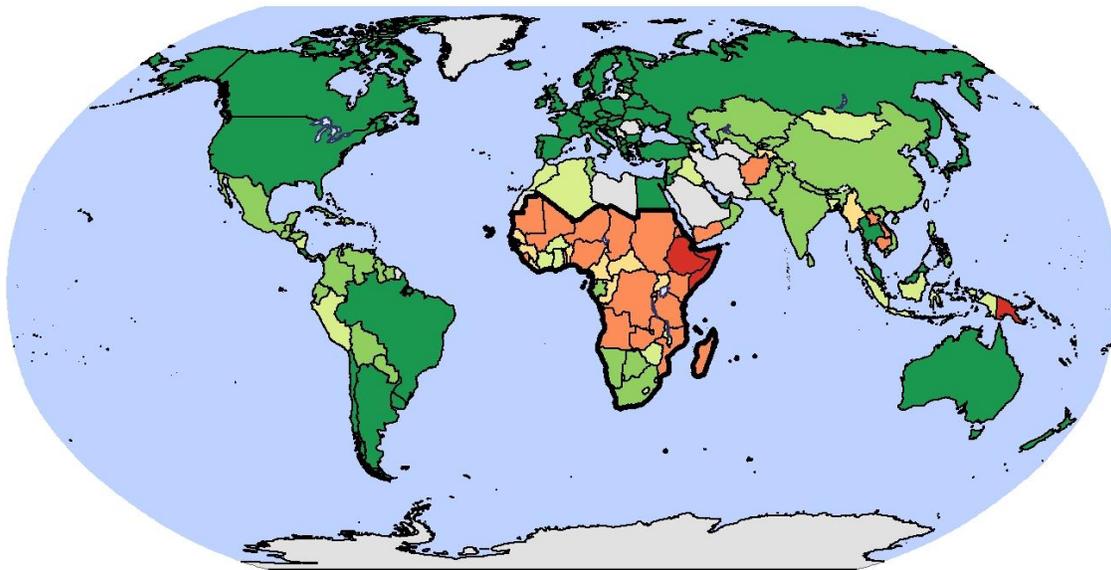


Figure 2.10 Africa’s hydropower potential is large

- **Water for people.** Often water resources are not the main constraint on water supply. Currently, only 60 percent of Africa’s people have sustainable access to improved

drinking water (WHO / UNICEF 2010). Approximately 25 percent of the African population experiences high water stress, sometimes because too little water is available but often because water supply systems are underdeveloped or poorly operated. About 69 percent of the population lives under conditions of relative water abundance (IPCC 2007). However, this relative abundance often coexists with low rates of access to clean drinking water and sanitation, which effectively reduce the quantity of fresh water available for human use.



#### Access to an improved water source in % of total population (in 2005-2009)



**Below world average (85.8%)**

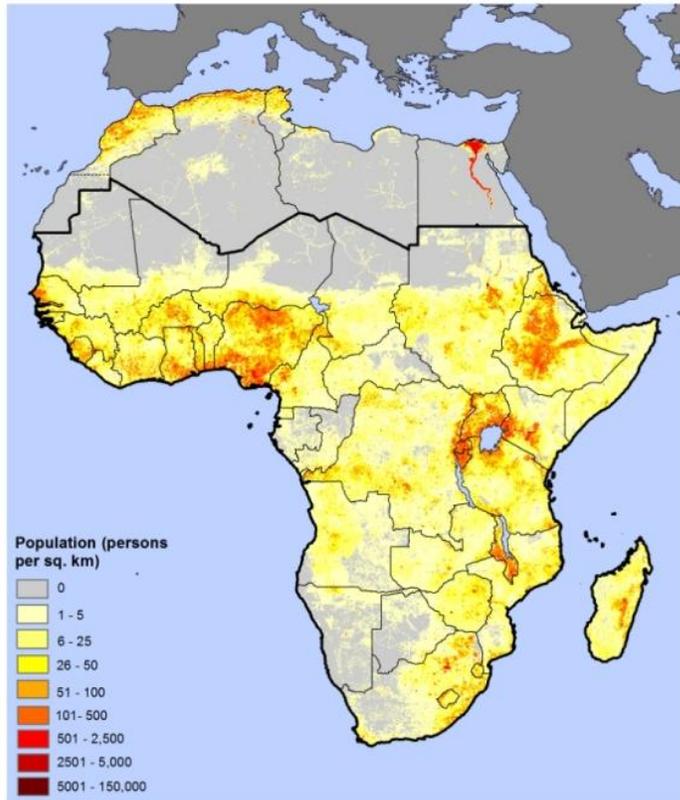
Source: Improved water source (WHO and UN Children's Fund, JMP, 2009), from the World Development Indicators, World Bank database.

**Figure 2.11 Africa lags the world in safe water supply**

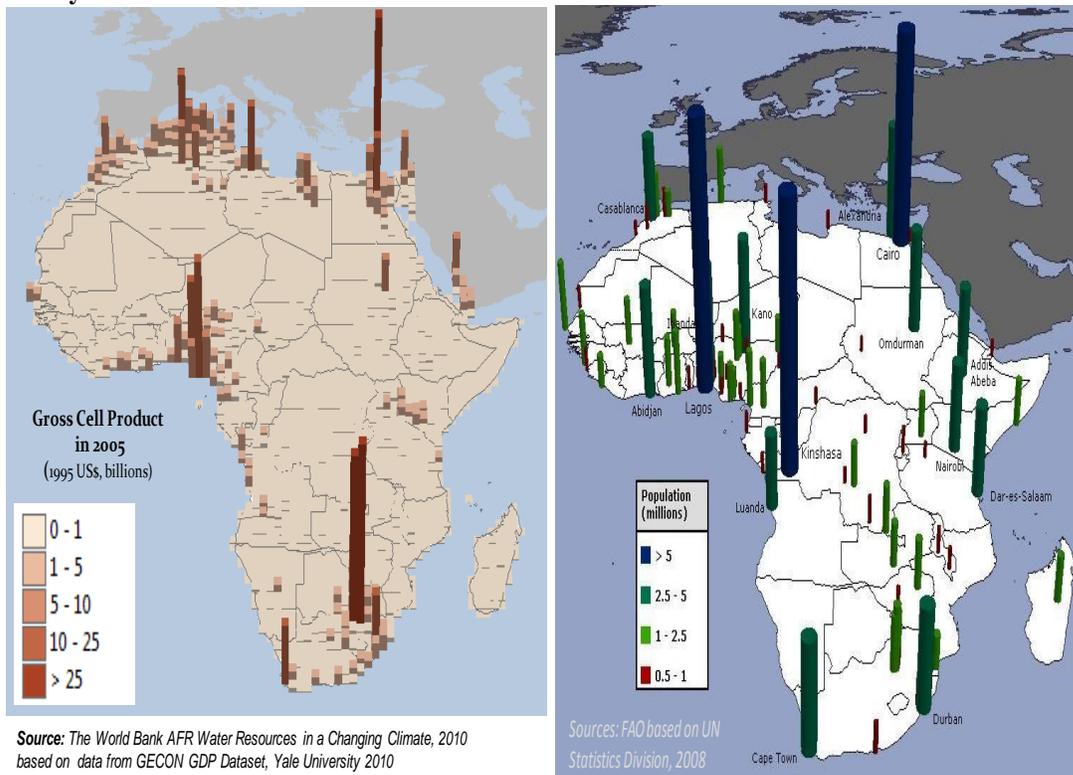
Despite considerable improvements in access to fresh water in the past few decades, almost 40 percent of the African population still has inadequate access to improved water sources (figure 2.11) and even fewer have access to improved sanitation facilities.

To reach the goal of providing 78 percent of Africa's people with safe drinking water by 2015, an additional 332 million people need to have access to improved drinking water sources. Similarly, 313 million Africans still lack access to adequate sanitation, increasing their exposure to disease.

Africa's largely low population densities make it difficult to provide basic water and sanitation services to widely dispersed populations (see figure 2.12). However, it is the most urbanizing region in the world and cities are growing very rapidly. These cities are also becoming the hub of economic activity (see figure 2.13).

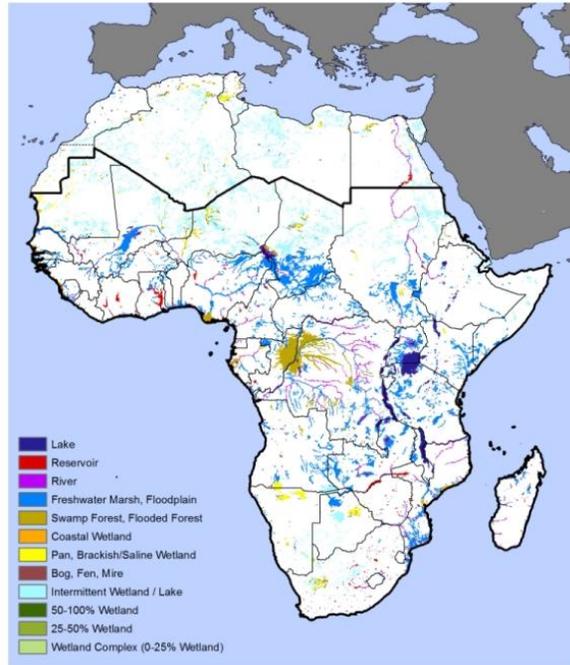


**Figure 2.12** Although population densities are relatively low in Africa, there are pockets of high density



**Figure 2.13** GDP and population distribution in Africa

- **Water for the environment.** The interaction of water, land, and climate plays a key role in creating habitats to sustain Africa's biodiversity and environmental services. Wetland areas in Africa are critical to local livelihoods and for global biodiversity (including the Congo, the Okavango, and Sudd wetlands, figure 2.14) and eco-tourism revenues. In such areas, it is essential that water resources be developed sustainably—integrating environmental, social, and economic considerations. Poverty and population pressures have resulted in land degradation and pollution, which have decreased the quality and quantity of fresh water resources in Africa.



**Figure 2.14 African wetlands**

To harness water's productive potential and manage its destructive power, the countries of Africa must deploy the right set of investments in information, institutions, and infrastructure. That is easier said than done. Water investment planning is weak and often a project-by-project approach fails to capture cross-sector and basin-wide implications. On occasion, transboundary basin agencies have taken steps towards enhancing cooperation in difficult environments (for example, joint asset development and management in Senegal's river basin authority (OMVS- L'Organisation pour la Mise en Valeur du fleuve Sénégal) , a sustainable development action plan and investment program in the Niger basin's Niger Basin Authority (NBA), and partial cooperation on the Nile and Zambezi). These transboundary and other national/sub-national agencies have done considerable work on improving the knowledge base and analytical tools in such basins. However, technical and management capacity still requires considerable improvement to adequately realize the ideas of integrated water resources management and climate risk management. The same is true in national water agencies, where vital instruments such as water rights and insurance have yet to be firmly established and water investments fall far short of needs. The case of Darfur (figure 2.15) illustrates how issues of climate and conflict combine to create complexities in water resources management and service delivery. Even where water and other resources are abundant, as in the Congo basin, conflict and insufficient development cause water services to remain at a low level.

The next chapter examines the historical variability of Africa's climate and the implications of that variability, particularly with regard to the destructive power of water.



Figure 2.15 In places like Darfur, water challenges are dire  
Source: World Bank, Darfur Water Resources Scoping AAA

## Chapter 3: Looking Back at Climate Variability

- Africa's climate shows considerable geographic variation.
- Historical climate variability has been high from season to season and from year to year.
- This high variability has impeded development in the continent.
- Africa has unique features that increase its vulnerability to climate risks.

**The African continent spans several climate zones.** The Köppen-Geiger climate classification system illustrates the diversity of Africa's climate (figure 3.1 and table 3.1). The continent can be divided into six subregions according to the three main Köppen climate classifications and the subregions' relative location to the equator. As can be seen by comparison with figure 2.12, most of the population of Sub-Saharan Africa lives in the equatorial zones, which are the regions most endowed with water resources. Many river basins cut across country boundaries as well as Köppen climate boundaries and include areas with widely varying climate and water characteristics.

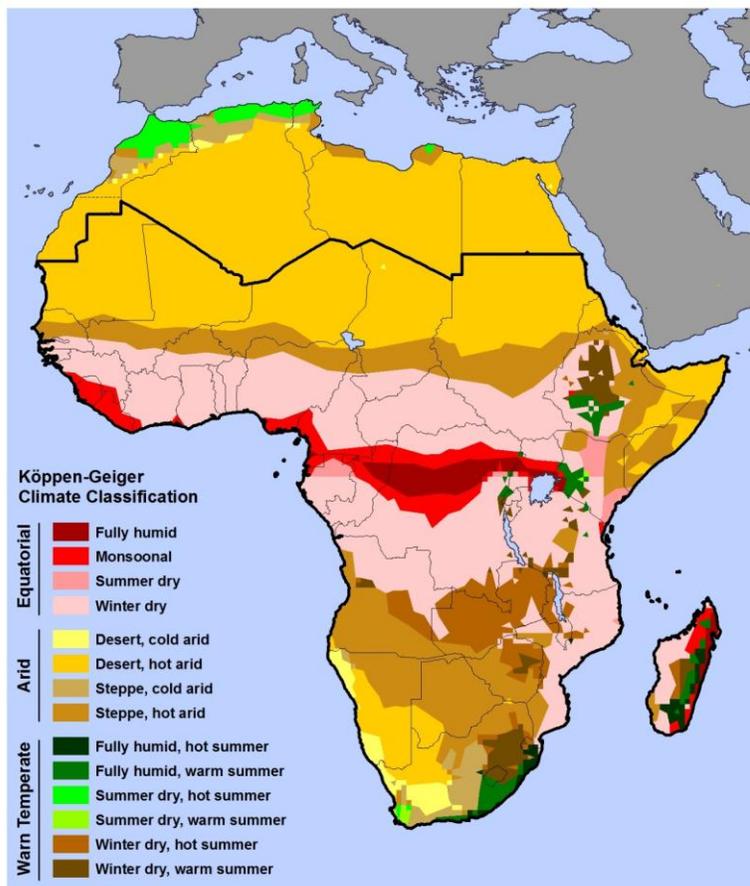
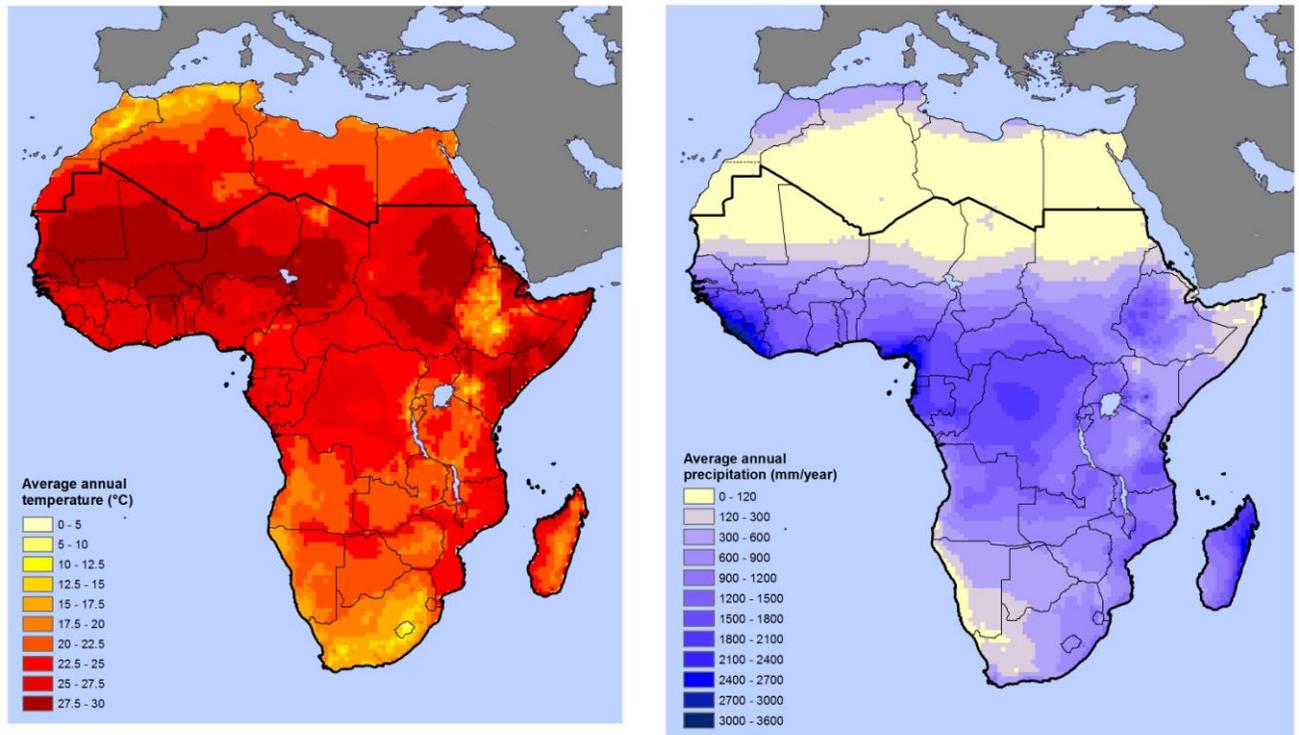


Figure 3.1 Köppen-Geiger climate classification of Africa and characteristics

**Table 3.1 Africa's countries by major Köppen-Geiger classification**

<b>Northern equatorial</b>
Burundi, Benin, Burkina Faso, Central African Republic, Cameroon, Chad, Congo, Congo DRC, Comoros, Cote d'Ivoire, Ethiopia, Gabon, Ghana, Guinea, The Gambia, Guinea-Bissau, Equatorial Guinea, Kenya, Liberia, Mali, Mauritius, Nigeria, Sudan, Senegal, Sierra Leone, Togo, Uganda
<b>Southern equatorial</b>
Angola, Congo, Congo DRC, Gabon, Kenya, Madagascar, Mozambique, Malawi, Rwanda, Somalia, Tanzania, Uganda, South Africa, Zambia, Zimbabwe
<b>Northern arid</b>
Benin, Burkina Faso, Central African Republic, Cameroon, Chad, Eritrea, Ethiopia, Kenya, Mali, Mauritania, Niger, Nigeria, Sudan, Senegal, Somalia
<b>Southern arid</b>
Angola, Botswana, Kenya, Madagascar, Mozambique, Namibia, Tanzania, South Africa, Zambia, Zimbabwe
<b>Northern warm temperate</b>
Burundi, Congo DRC, Ethiopia, Kenya, Swaziland, Uganda
<b>Southern warm temperate</b>
Angola, Congo DRC, Kenya, Lesotho, Madagascar, Mozambique, Malawi, Rwanda, Tanzania, Uganda, South Africa, Zambia, Zimbabwe

***Africa's climate has also been highly variable over time.*** The climate varies greatly within each year, with distinct seasonality, and equally greatly from year to year (see figures 3.3 and 3.4). The continent's climatic zones range from humid equatorial regimes, seasonally arid tropical regimes, to subtropical Mediterranean climates. Each climatic zone exhibits different degrees of variability in rainfall and temperature (see figure 3.2).

**Figure 3.2 Spatial variation of temperature and precipitation in Africa (1901-2006)**

Source: CRU Dataset (University of East Anglia Climate Research Unit, 2009)

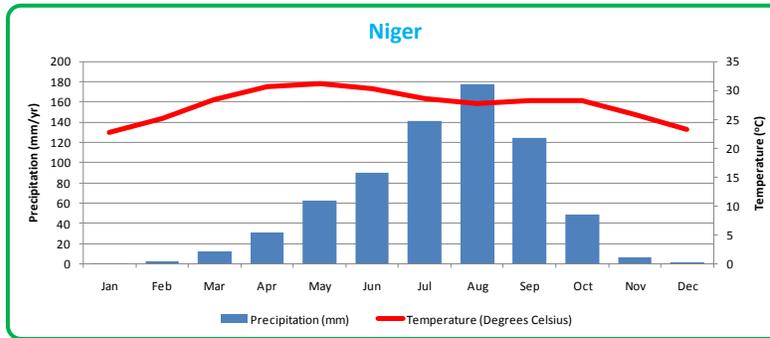


Figure 3.3 Month-to-month climate variability in the Niger basin

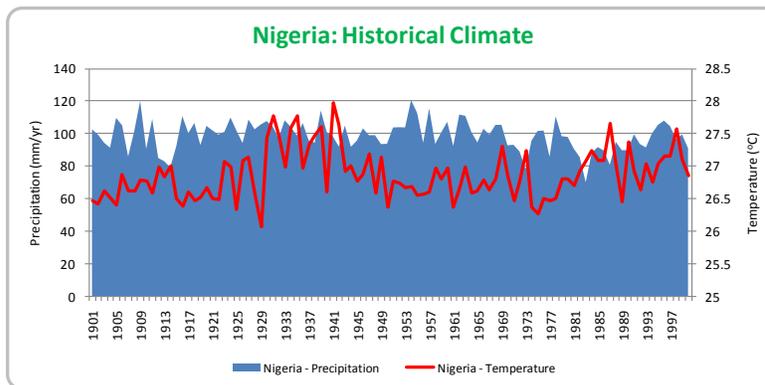


Figure 3.4 Year-to-year climate variability in Nigeria

**Africa's variability in climate means variability in water resources.** The relationship between runoff and precipitation is complex. The high variability of precipitation and temperature across Africa translates into widely varying runoff, with basins such as the Congo displaying extremely high runoff and the arid and semi-arid regions of the Sahel, Sudan, Egypt, and southern Africa displaying very low runoff (figure 3.5).

The situation is similar over time, with much of Africa being susceptible to significant changes in runoff and flows within and across years. Although variability in rainfall from year to year is great over most of Africa, some regions—notably the Sahel—show substantial variability from decade to decade. By contrast, eastern and southeastern Africa show relatively stable patterns.

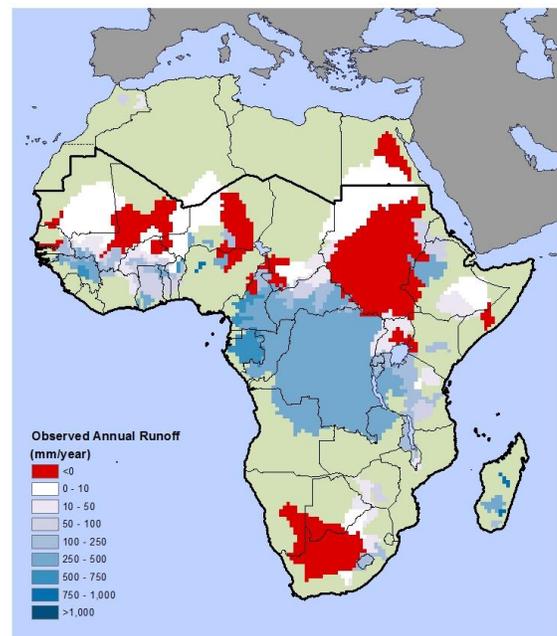
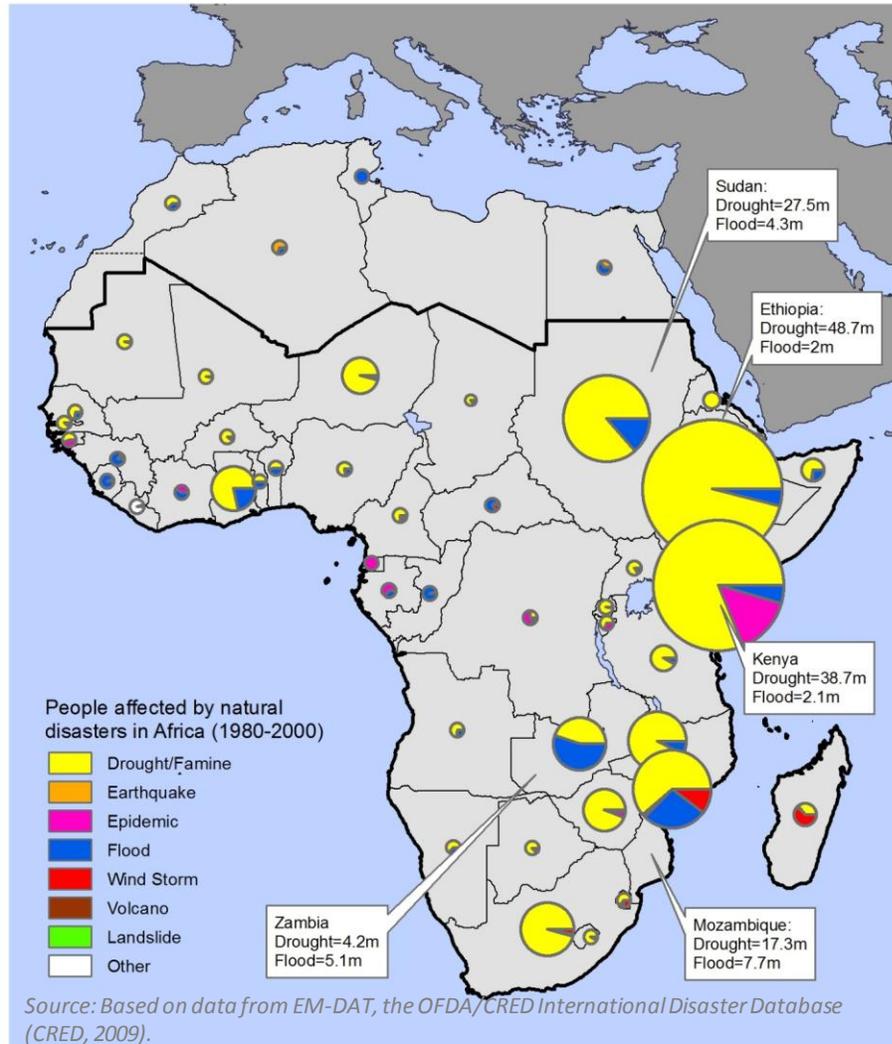


Figure 3.5 Runoff is high in sub-basins of the Congo basin and parts of West Africa (source: Composite runoff fields V1.0 (UNH / GRDC, 2000))



**Figure 3.6 Many African countries are routinely devastated by droughts and floods**

The magnitude of temporal variations in rainfall is significant because its manifestations, such as floods and severe droughts, can be extreme. Temporal variation in temperature can stress water resources through higher evaporation rates, especially in semi-arid and arid areas.

**Hydrologic variability causes droughts and floods that can have dramatic social, economic, and environmental effects.** Africa's great climatic and hydrologic variability is manifested as droughts and floods that destroy livelihoods and undermine economic progress. Variability also discourages investment and encourages other risk-averse behavior that aggravates the poverty trap. It is no coincidence that in many of the world's poorest countries, climate variability is high, water-related investments are relatively limited, and there is often a strong correlation between rainfall variability and GDP, with GDP dropping 10 percent or more at times because of this variability. Most of the natural disasters in Africa result from climate risks, primarily drought (figure 3.6), and large areas throughout Africa are susceptible to droughts and floods. For example, a large proportion of Kenya routinely suffers from both floods and droughts, often in the same year (figure 3.7), and stream flow in the Niger River and its tributary, the Benue River, have varied greatly since 1900 (figure 3.8).

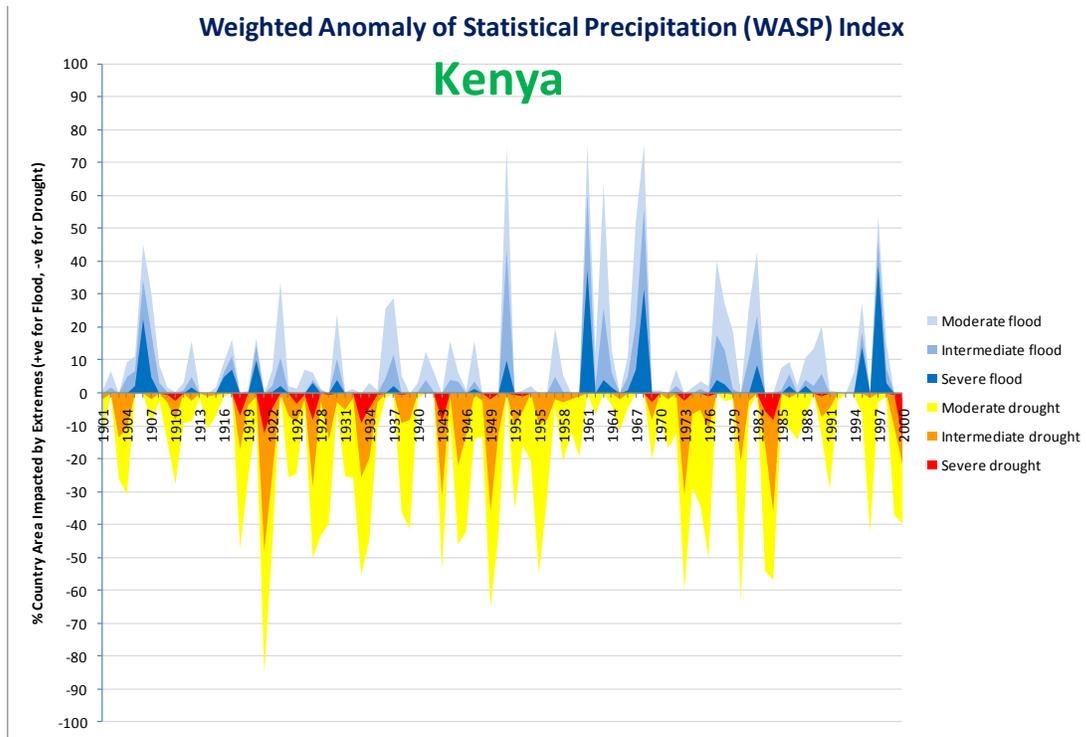


Figure 3.7 Kenya: a history of floods and droughts

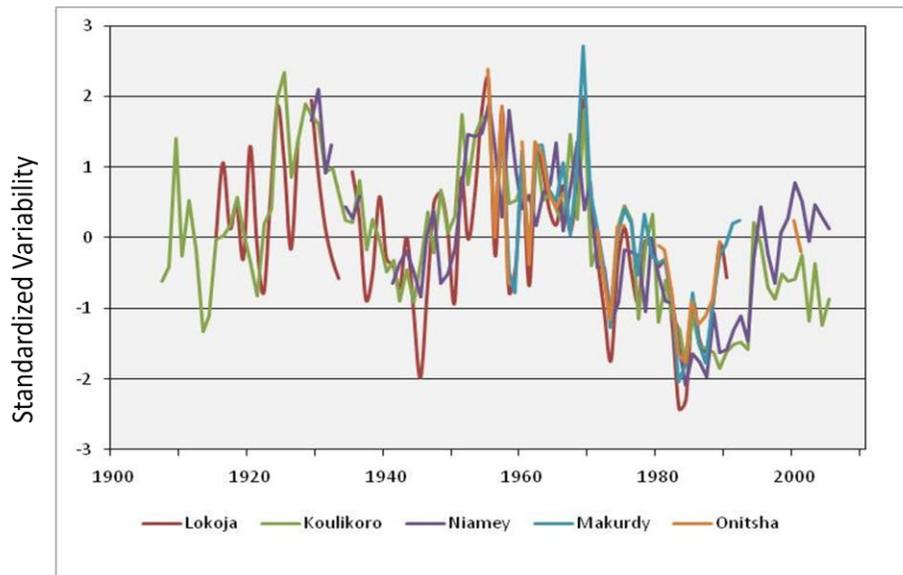


Figure 3.8 Comparison of stream flow variability along the Niger River and Benue Tributary

Other types of natural disasters, such as coastal storms, affect a small area of southeastern Africa (figure 3.10). Such storms often spell disaster in Madagascar and Mozambique. Storm-related floods are recurrent in some countries of Africa—even communities located in dry areas have been affected. Huge floods occurred in Mozambique—particularly along the Limpopo, Save, and Zambezi valleys—in 2000 and 2001. The floods of 2000 claimed 700 lives and left a million people homeless. They also destroyed crops, disrupted electricity supplies, and destroyed roads, homes, and bridges. It is not uncommon for some countries to experience both droughts and floods in the same year. Recent floods in East Africa

were followed by periods of extended drought. Ethiopia, for example, experienced drought early in 2006, but in August of the same year severe floods killed more than 200 people (Osman-Elasha 2006).

All of these climate risks—combined with high population exposure, poor buffering to climate and resultant hydrologic risks, and poor forecasting and coping capacity—can severely undermine the economic progress needed to help countries achieve their development goals. The “lumpy” nature of extreme events makes it difficult to predict which economies will be most affected, as effects are a function of both institutional capacity and serendipity. However, some countries in Africa (Ethiopia in figure 3.9) have recently begun to reduce the sensitivity of their agricultural economy to the vagaries of rainfall. This increased resilience has resulted from increasing investments in agriculture and watershed management as well as improved linkages to credit and alternative livelihood activities.

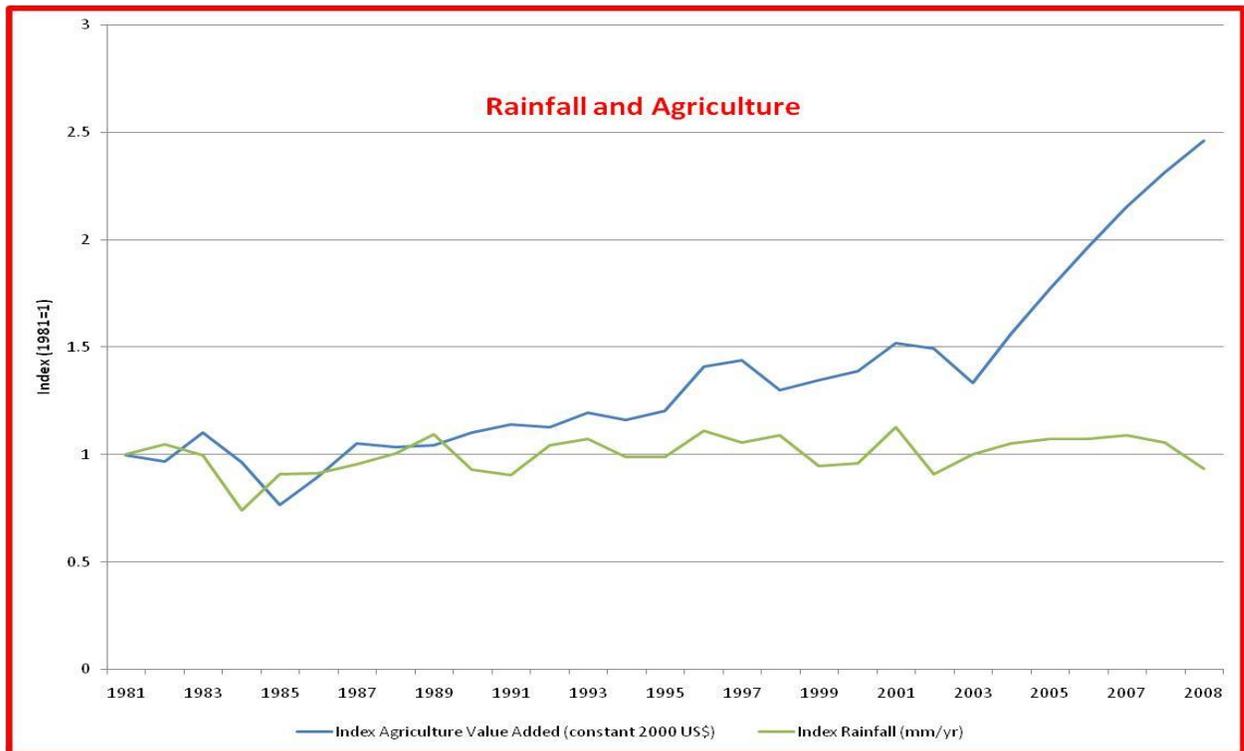
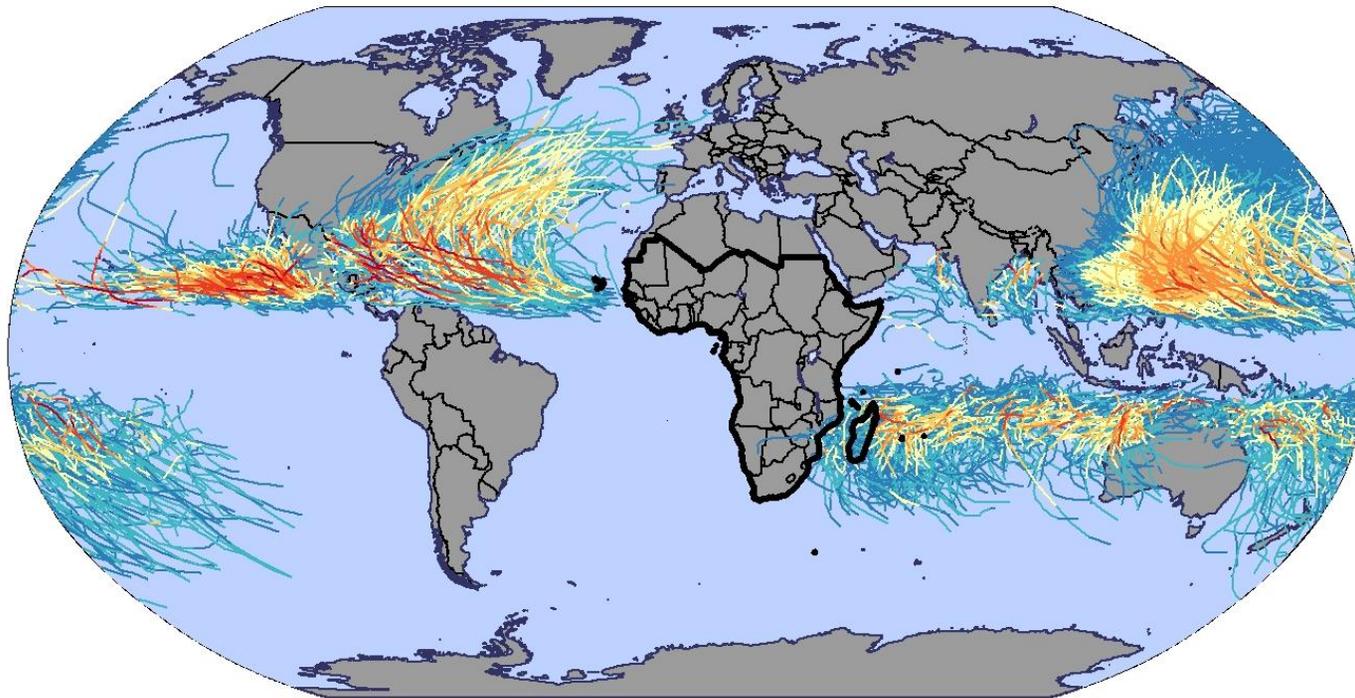


Figure 3.9 Gradually breaking the variability curse

### Tracks and Intensity of Tropical Storms from 1980 to 2006 included.



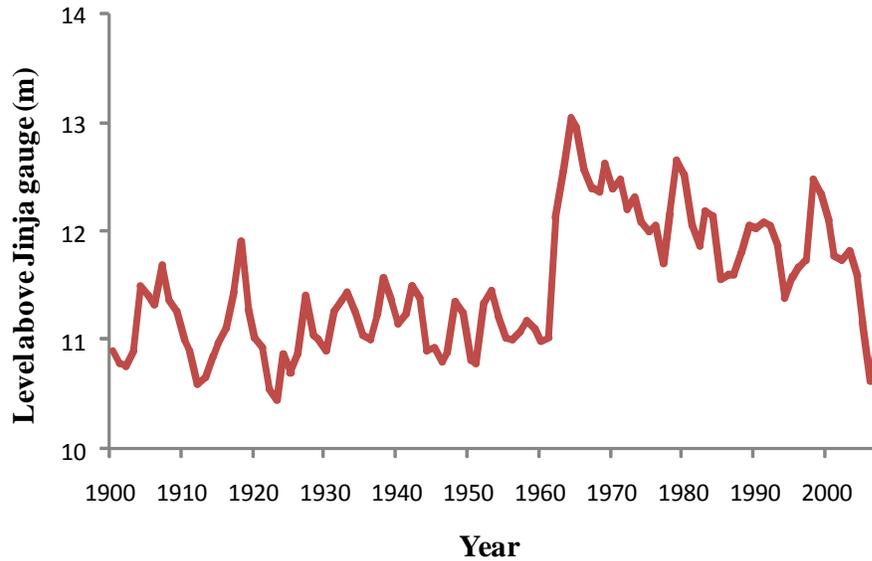
#### Saffir-Simpson Hurricane Intensity Scale



Source: *Cyclones tracks and intensity (UNEP/DEWA/GRID-Geneva, 2007)*

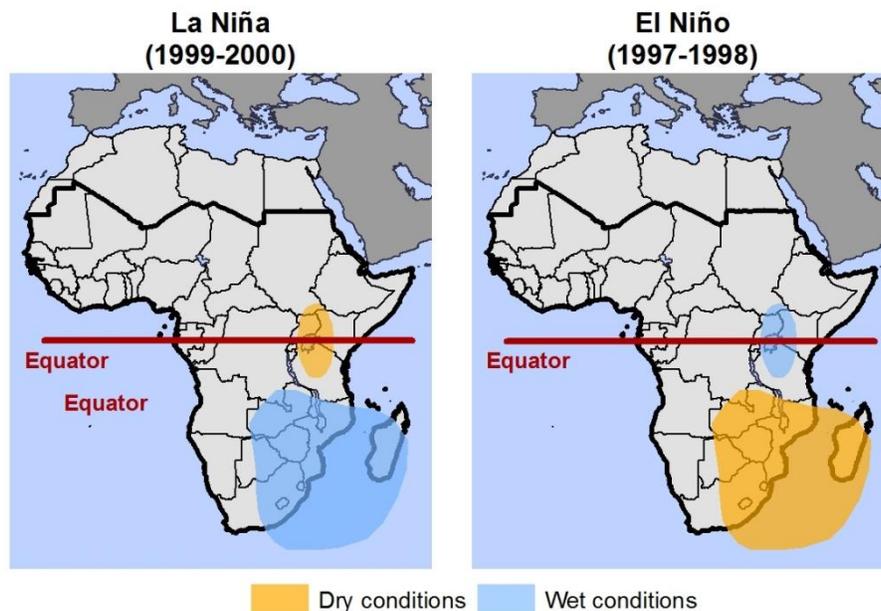
Figure 3.10 Tracks and intensity of tropical storms—storm impacts are localized in southeastern Africa

**The climate has always been changing.** Long-term records indicate that flows in river systems such as the Nile have always varied widely—with significant socioeconomic consequences. The same appears to be true for levels in lakes such as Lake Victoria (figure 3.11) that demonstrate high season-to-season and year-to-year variations. Many theories have been put forward to explain the historic variations (such as the significant rise in the early 1960s), including a high degree of correlation with sunspot cycles. In the last few years, levels in Lake Victoria have been significantly influenced by the ineffective operation of hydropower infrastructure at the lake outflow.



**Figure 3.11** Levels in Lake Victoria have varied significantly over time in response to climatic phenomena

Year-to-year and decade-to-decade phenomena such as the El Niño-Southern Oscillation (ENSO) also have a significant impact on African hydrology (figure 3.12).



Sources: Based on information from UNEP-GRID, from the Climate Prediction Center - NCEP

**Figure 3.12** The ENSO phenomenon also influences Africa's climate

Figure 3.13 depicts the strong relationship between El Niño years with drought and famine conditions in Ethiopia. Although those conditions have exacted a devastating toll on the population and required continued food aid for the country, the predictability of the pattern suggests that better forecasting of hydrologic extremes could allow for better preparation.

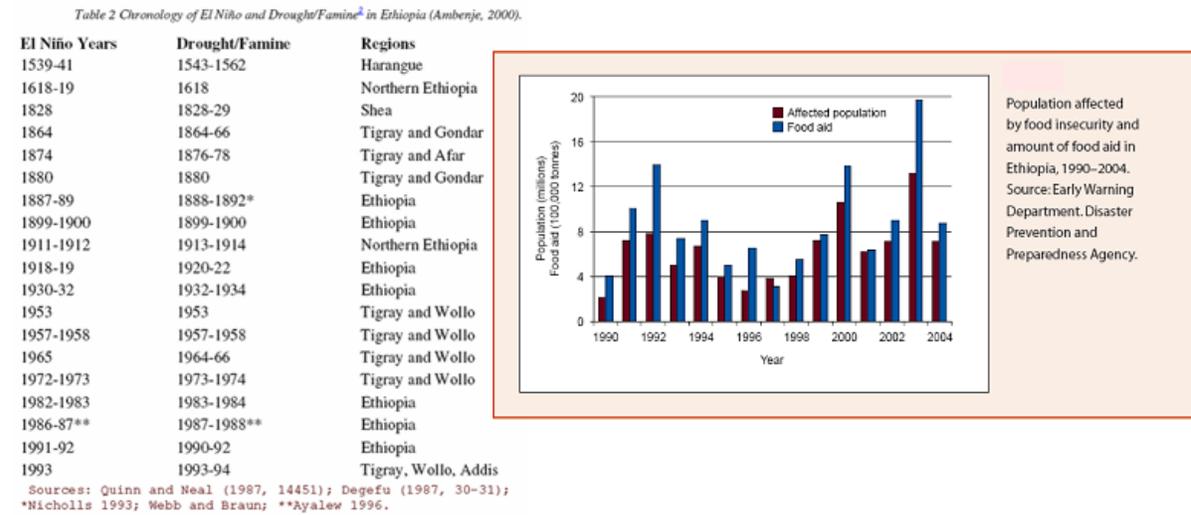


Figure 3.13 Ethiopia's devastating droughts are strongly correlated with El Niño

Precipitation and temperature have changed substantially over the past century. Over the past century, the Sahel has become much drier, causing desertification. East Africa has become commensurately wetter, while the southern region has become drier. There are significant variations within each river basin, reflecting the high historical variability (e.g. for precipitation in figure 3.14).

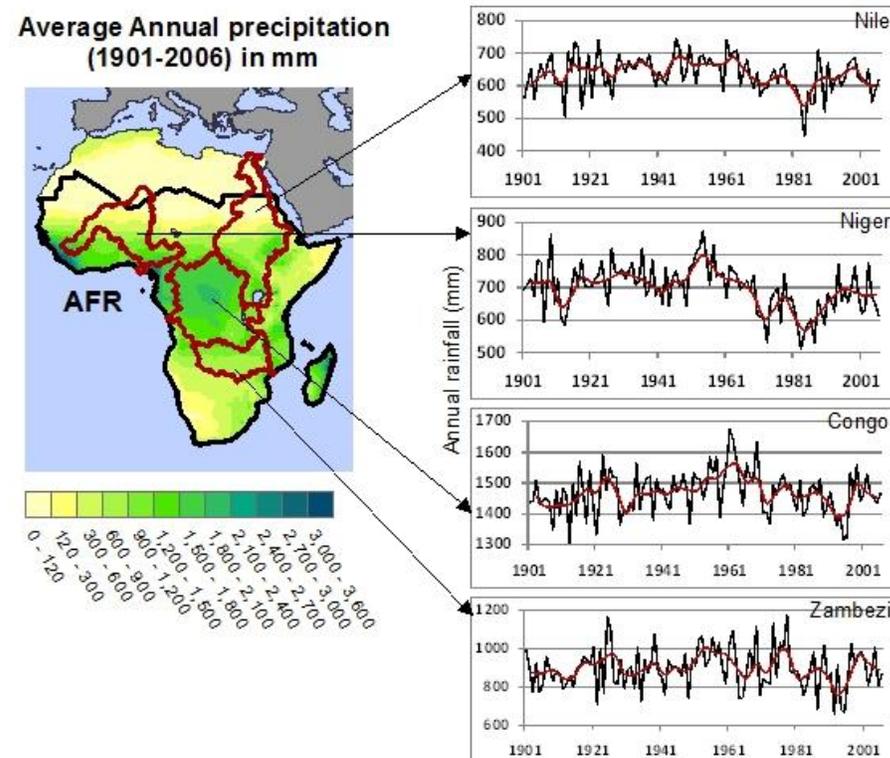


Figure 3.14 Trends in annual rainfall (mm)  
Source: CRU Dataset (University of East Anglia Climate Research Unit, 2009)

The average temperature in Africa rose by 0.5°C over the past century. Six of the warmest years on record have occurred since 1987. In East Africa, and southeastern Africa, temperatures during the 1990s were higher than earlier in the century. Although warming is dominating Africa overall, the greatest warming is over the interior of southern African and in the Mediterranean countries of northwest Africa. There are some areas which have become cooler around Nigeria and Cameroon in West Africa and along the coastal margins of South Africa, Senegal, and Mauritania.

Looking back on the high variability of the region's climate, it is reasonable to assume that the future also holds a highly variable (and uncertain) climate for Africa —even without new trends due to climate change. Adaptation to this historical variability has been very insufficient in Africa. Much needs to be done to address the variability in the historical record.

**Africa has unique characteristics that make it susceptible to climate variability and change** (box 3.1). Many of these characteristics make it vulnerable to the current climate variability (as illustrated by the historic record). In addition, some characteristics such as low lying, highly populated coastal areas, make it vulnerable to further climate change, such as a rise in sea levels.

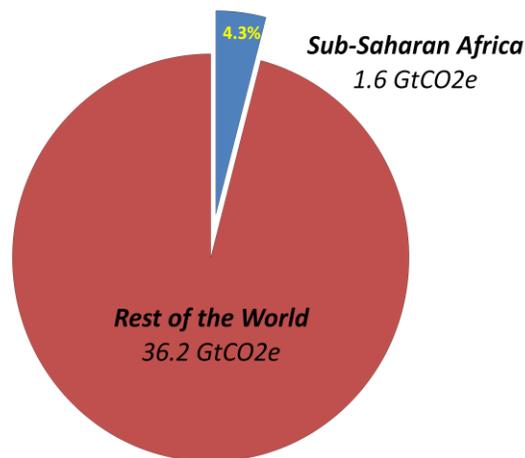
### Box 3.1 What makes Africa particularly vulnerable to climate risks?

- **A low level of development and widespread poverty.** The limited financial and human resources and lack of coping capacity make it difficult for economies and populations to adapt to changing climate. Climate risks affect the poor disproportionately, because wealthier economies (and communities) are in a better position to cope with climate risks and changes in those risks.
- **A high degree of variability in climate and hydrology.** Africa shows a high degree of climate variability, both geographically and over time. Climate change is expected to exacerbate that variability. African countries have the highest vulnerability to drought of any world region, with an estimated one-third of the population living in drought-prone areas. Around 220 million people are annually exposed to drought. The African Sahel, situated at the southern fringe of the Sahara desert and stretching from the West African coast to the East African highlands, is particularly prone to drought. Droughts have also affected the Horn of Africa and southern Africa since the late 1960s. In 2005 droughts in these two subregions threatened the lives of more than 14 million people from Ethiopia and Kenya to Malawi and Zimbabwe. In the following year, drought gave way to extensive flooding across many of the same countries (ECOSOC 2007).
- **The substantial exposure of economies and livelihoods to climate.** Much of the African economy is hostage to climate-related hydrologic variability. Agriculture—the main livelihood of the largely poor population and a very large part of the GDP of many of Africa’s countries—is largely rainfed and thus highly dependent on the vagaries of climate. The performance of other sectors (hydropower and even irrigated agriculture) also depends on water resources staying within rather narrow bounds.
- **A long, populous coastline.** Africa contains many countries with large populations living near the coast, such as The Gambia, where approximately 91 percent of the population lives within 100 kms of the coast. Africa’s long coastline and some small islands are particularly vulnerable to climate change—from the rise of sea levels (which threaten to inundate and cause the salinization of coastal aquifers) and from changes in upstream hydrology. Although this latter factor is not as significant as in other parts of the world, localized impacts will be complicated by high population densities in coastal deltas and poor coping capacity.
- **A poor knowledge base on climate and hydrology.** Africa lags far behind the rest of the world in hydro-climatological networks and related decision-support and communication tools (including rainfall, flood, drought, and storm forecasting). These deficits increase the vulnerability of populations to climate risks that are effectively managed elsewhere in the world.
- **Weak institutional capacity and policies.** The region also faces significant governance challenges, including the institutional and policy frameworks needed for effective climate-risk management. On the institutional front, the problems include poor staff skills, weak analytical and implementation capacity in water-related institutions, and weak partnerships with other agencies, universities, nongovernmental organizations, and private firms working in related areas. On the policy front, policies to promote integrated water resources management, accelerated sustainable development, and to provide flexible instruments to better cope with climate risks (such as disaster insurance and well defined water entitlements) are still in their infancy. Once in place, such instruments encourage scaled-up investments for broad-based, sustainable growth.
- **A multitude of international river basins.** Much of Africa’s water is tied up in international river basins. This means that effective management of water resources at the river basin level (the logical unit of water management) is complicated by the need to coordinate with other riparian states to develop a shared vision for the management of valuable water resources. A corollary is that effective management of climate risks (and opportunities) also requires transboundary cooperation.
- **Other pressing development concerns.** Coping with climate stresses in Africa is complicated by many other basic challenges (poverty, subsistence livelihoods, development needs) and many changes unrelated to climate (such as population growth, land use changes, increasing water demands owing to growth) that all place demands on limited budgets and human resources. In fact, Africa’s development needs will require huge investments in irrigated agriculture, hydropower, and water supply that may exacerbate the hydrologic stress of the region and its vulnerability to climate change.

## Chapter 4: Looking Ahead at Climate Change

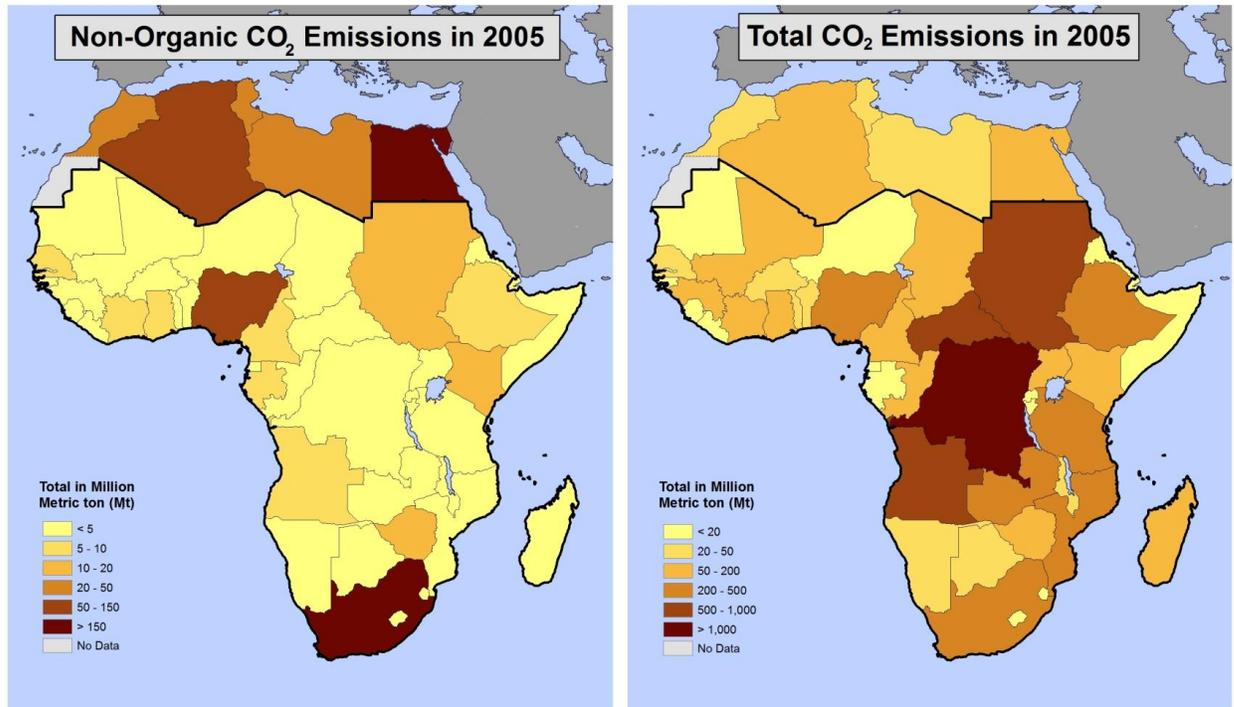
- *Climate change is caused by increasing levels of greenhouse gases (GHGs), such as CO<sub>2</sub>.*
- *Africa contributes little to the global increase in GHGs. What little it does add comes from fossil fuel burning in a few countries and from land use change in others. However, it has a significant role to play in terms of maintaining and enhancing carbon sequestration in forestry and agriculture as a contribution to GHG mitigation efforts.*
- *However, Africa will face the effects of climate change—primarily through temperature increases, precipitation changes, and a higher sea level.*
- *Although there is consensus that the climate is changing, climate models do not agree (especially on precipitation projections) for the continent, making adaptation planning complex and difficult.*
- *African water use depends on direct precipitation (in rainfed agriculture), runoff and groundwater recharge, all of which are difficult to assess in a changing climate.*

**Climate change refers to variations in the earth's climate that can be attributed directly or indirectly to human activity** that increases the concentration of greenhouse gases (GHG) in the atmosphere. Africa contributes very little to the production of these GHGs (see figure 4.1). What little it does contribute comes from substantial fossil-fuel (non-organic carbon emissions) burning in South Africa and Nigeria and from changes in land use (organic carbon emissions) as shown in figure 4.2. However, Africa has a significant role to play in global mitigation efforts, especially from preserving and enhancing carbon sequestrations in forests (especially in the Congo basin) and in agricultural systems through proposed REDD+ systems.



**Figure 4.1 Greenhouse gas emissions (excluding land use) in 2005**

Nevertheless, Africa is likely to be significantly affected by climate change. The Intergovernmental Panel on Climate Change (IPCC) has provided four assessments of global climate change. The Fourth Assessment Report (IPCC 2007) found that human activity over the past century had greatly increased the amount of GHGs in the atmosphere, contributing to an average temperature increase of 0.74°C. Having examined many plausible scenarios of climate change (based on efforts made to control GHG emissions), the IPCC has estimated several scenarios of temperature rise and the implications of those scenarios for precipitation patterns, sea levels, and other climate-related phenomena.

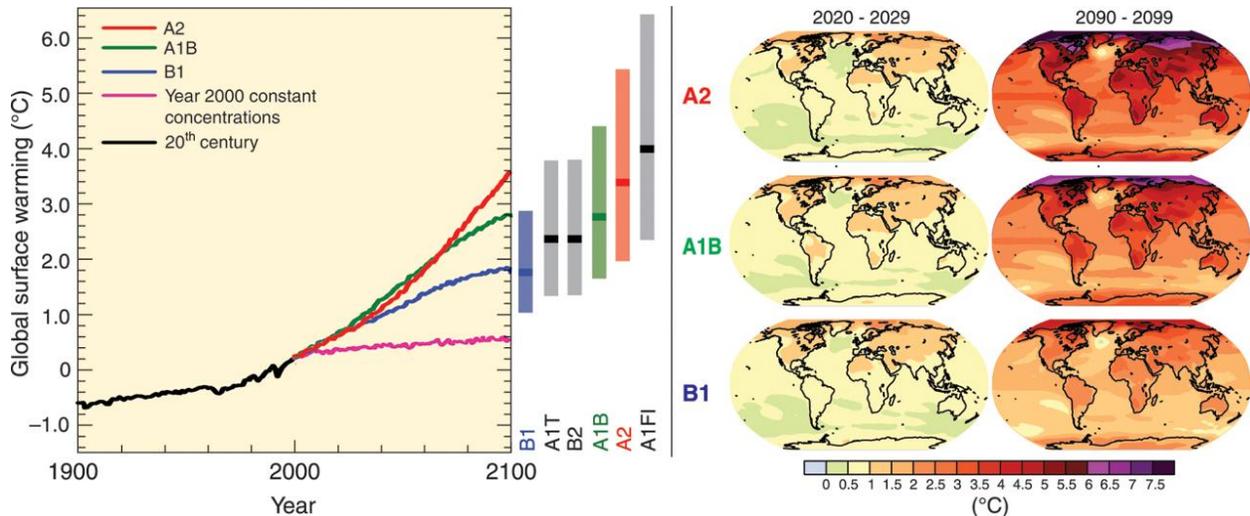


Source: Based on data from Climate Analysis Indicators Tool (CAIT) Version 7.0. (Washington, DC: World Resources Institute, 2010)

**Figure 4.2 Land use change is a significant part of African GHG emissions**

***The world's climate is expected to change substantially, with changes in temperature, precipitation, sea levels, and storms and with subsequent effects on hydrology.*** The initial manifestation of climate change is expected to be a rapid rise in temperatures over the globe in the likely range of 1.1 to 6.4°C. Precipitation patterns are expected to change significantly, and extreme weather events (severe storms, floods, droughts, and heat waves) are expected to become more intense and frequent. Sea levels are also expected to rise<sup>1</sup> by 18 to 59 cm by 2100, although some estimates are higher depending on scenarios of Greenland and Antarctic ice melting. These changes can already be observed—the IPCC's Fourth Assessment report indicates the possibility of widespread changes in extreme temperatures, longer and more intense droughts, greater frequency of heavy precipitation over most land areas, and contractions of Arctic Sea ice (2.7 percent per decade). Change in runoff is a key indicator of the potential impact of climate change on the water sector, with cascading effects on critical economic sectors and livelihoods.

<sup>1</sup> Sea levels can also change due to a combination of factors such as tectonic movement and oceanic currents. It is possible that a larger rise in sea level (>1m) could be observed by 2100, if there is enhanced polar ice and glacial melting (Overpeck et al., 2006), but this is considered by some analysts to be of low probability (Vaughan and Spouge, 2002), although recent measurements have indicated faster melting of Arctic ice than expected.



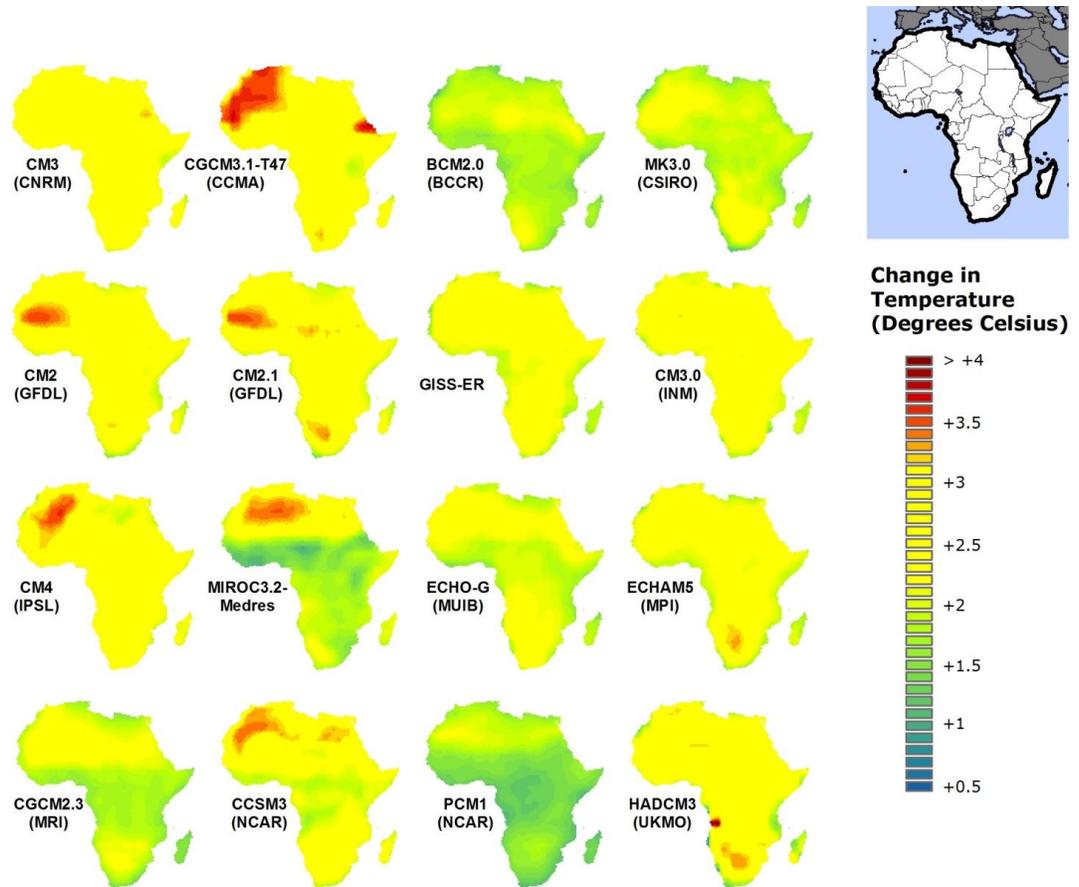
Left panel: Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090-2099 relative to 1980-1999. The assessment of the best estimate and likely ranges in the bars includes the Atmosphere-Ocean General Circulation Models (AOGCMs) in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. Right panels: Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999. The panels show the multi-AOGCM average projections for the A2 (top), A1B (middle) and B1 (bottom) SRES scenarios averaged over decades 2020-2029 (left) and 2090-2099 (right).

**Figure 4.3 Estimates of global warming vary substantially**

Source: IPCC 2007, p 46.

### Changes in the climate by 2100: the African context

**Temperatures are expected to rise.** According to the IPCC's mid-range scenario (A1B), by the end of the century Africa's average temperature will have risen by 3–4°C over the 1980-1999 period (figure 4.3), with the greatest rise occurring in the semiarid margins of the Sahara and central southern Africa and the smallest rise in the equatorial latitudes and coastal areas. The spatial distribution of estimated temperature changes across GCMs for the A2 SRES (Standard Reference Emission Scenario of IPCC) is presented in figure 4.4. Although all models agree that temperatures in Africa will increase, there is considerable spatial variation in projected magnitude of the change, and consequently its effect on evaporation, crop water requirements, etc.

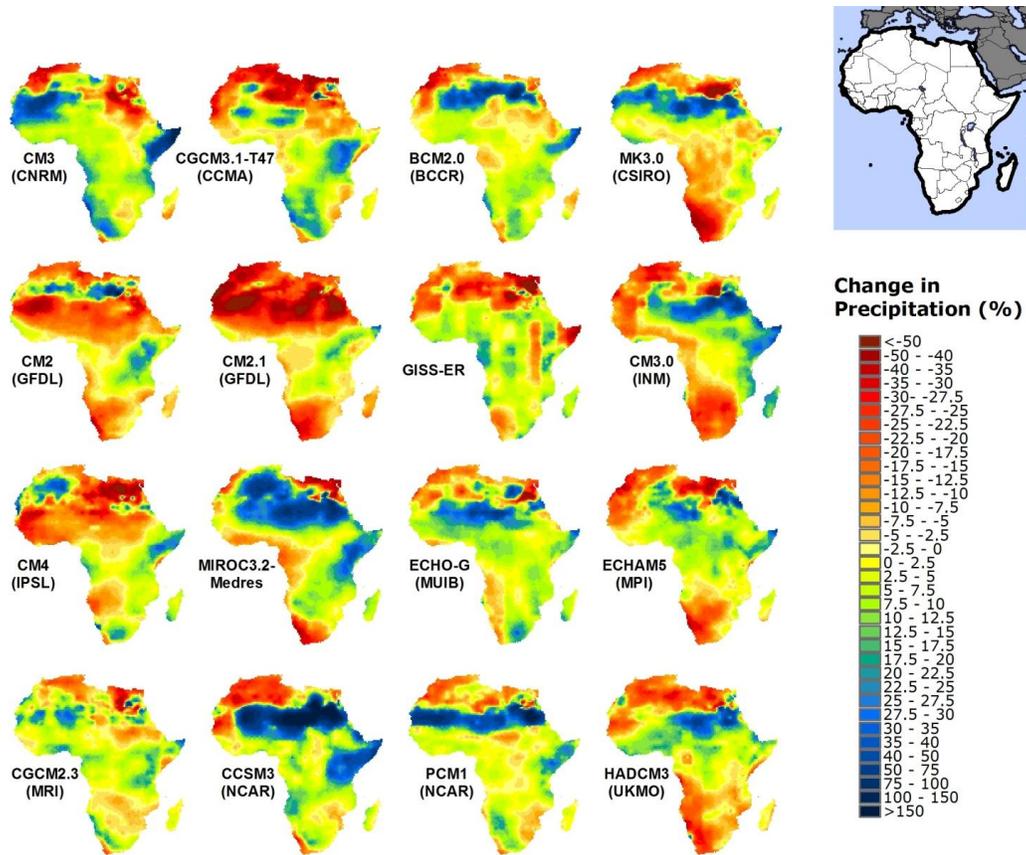


This map shows the temperature change projected by the considered climate model, under the A2 scenario for 2040 - 2069 as compared to 1961 - 1990. Map displays gridded data (cell size=0.5dd).

Sources: Based on data from the Climate Wizard (<http://www.climatewizard.org> developed by The Nature Conservancy, The University of Washington, and the University of Southern Mississippi).

**Figure 4.4 Models agree temperatures will increase but the level and the spatial distribution of the increase vary considerably across models**

**Precipitation patterns may change.** The relationship between changes in the globe's average temperature and the regional climate change is very uncertain, especially with regards to precipitation. Recent climate models provide conservative (although uncertain) projections for changes in precipitation. The resulting projections of precipitation change for Africa are shown in Figure 4.5 under the same A2 scenario (as used in Figure 4.4) and the same set of GCMs. Unlike the temperature projections, that at least agree on the direction of change, precipitation projections do not agree on either the direction or the spatial distribution of the changes. In addition, there are other climate phenomena not well understood or reflected in current GCMs that may add additional uncertainty – e.g. the precipitation in West Africa and the Horn of Africa and South-West Africa are strongly influenced by teleconnections especially El Nino Southern Oscillation (ENSO) and IOD (Indian Ocean Dipole).

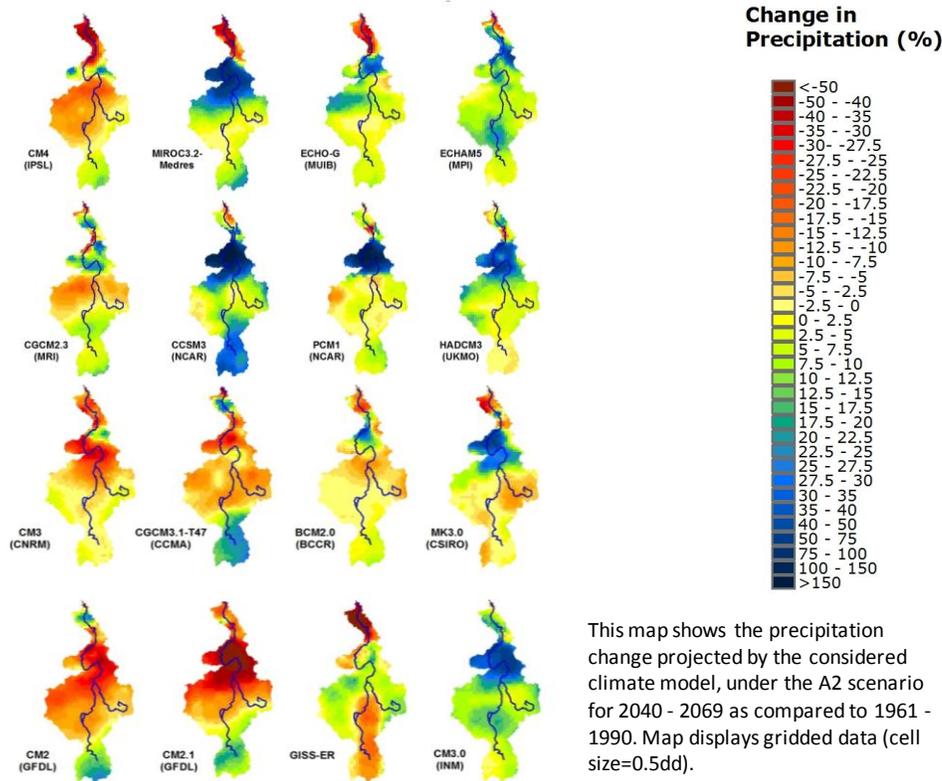


This map shows the precipitation change projected by the considered climate model, under the A2 scenario for 2040 - 2069 as compared to 1961 - 1990. Map displays gridded data (cell size=0.5dd).

Sources: Based on data from the Climate Wizard (<http://www.climatewizard.org> developed by The Nature Conservancy, The University of Washington, and the University of Southern Mississippi).

**Figure 4.5** Precipitation change in Africa by the 2050s—which GCM is right?

### Precipitation Scenarios in the Nile Basin for 2050s

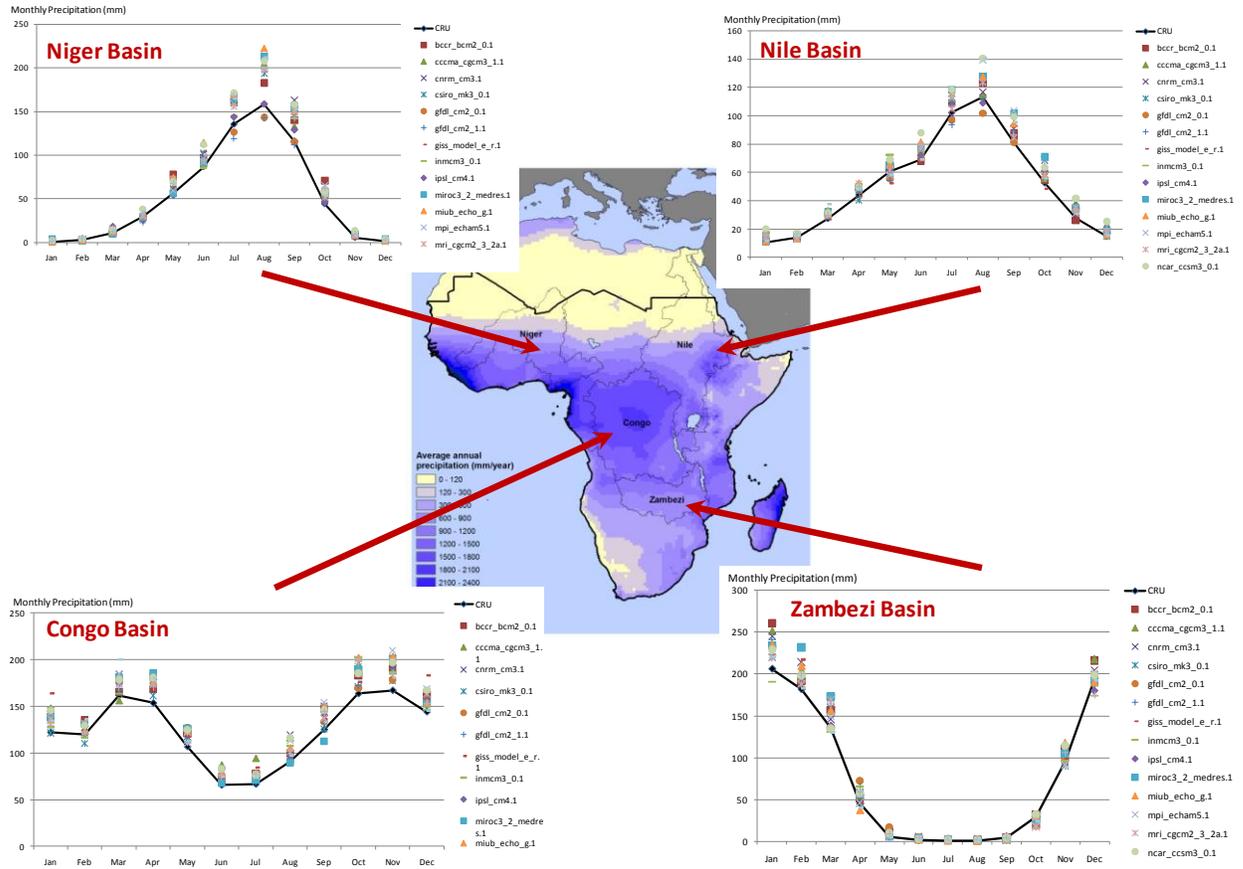


This map shows the precipitation change projected by the considered climate model, under the A2 scenario for 2040 - 2069 as compared to 1961 - 1990. Map displays gridded data (cell size=0.5dd).

Sources: Based on data from the Climate Wizard (<http://www.climatewizard.org>) developed by The Nature Conservancy, The University of Washington, and the University of Southern Mississippi)

**Figure 4.6 Different crystal balls tell different fortunes for the Nile Basin**

**Often in climate change analysis, one, a few, or the “median” projection is chosen to represent the precipitation future.** It is difficult to use such a limited set of results from the current set of General Circulation Models when making operational decisions because the divergence among these models (considered “equally likely” by the IPCC) is so great, especially for the critical precipitation estimates (figure 4.5 and figure 4.6). The lack of agreement makes it unreasonable to rely on any one precipitation scenario for Africa. This is illustrated in Figure 4.7 in which the historical average monthly precipitation is shown for four rivers basins in Africa. Also shown is the average monthly precipitation as projected by individual GCMs in each of the four basins. Note the consistently wide variation in projected monthly rainfall in which the range of values encompasses the historical average in most cases. Another illustration of the variability of precipitation projections is shown in Figure 4.8. Here the time series of historical annual precipitation for the twentieth century is shown against the individual time series projections from the GCMs. Note that the historic extremes of high and low precipitation equal or exceed the projected extremes. This suggests that the best first step is to ensure that water resource systems are able to cope with historic precipitation variability.



Sources: Based on Historical data from the Climate Research Unit (University of East Anglia) and GCM data from the Climate Wizard (<http://www.climatewizard.org>) developed by The Nature Conservancy, The University of Washington, and the University of Southern Mississippi

Figure 4.7 Historical and projected monthly precipitation for four river basins in Africa.

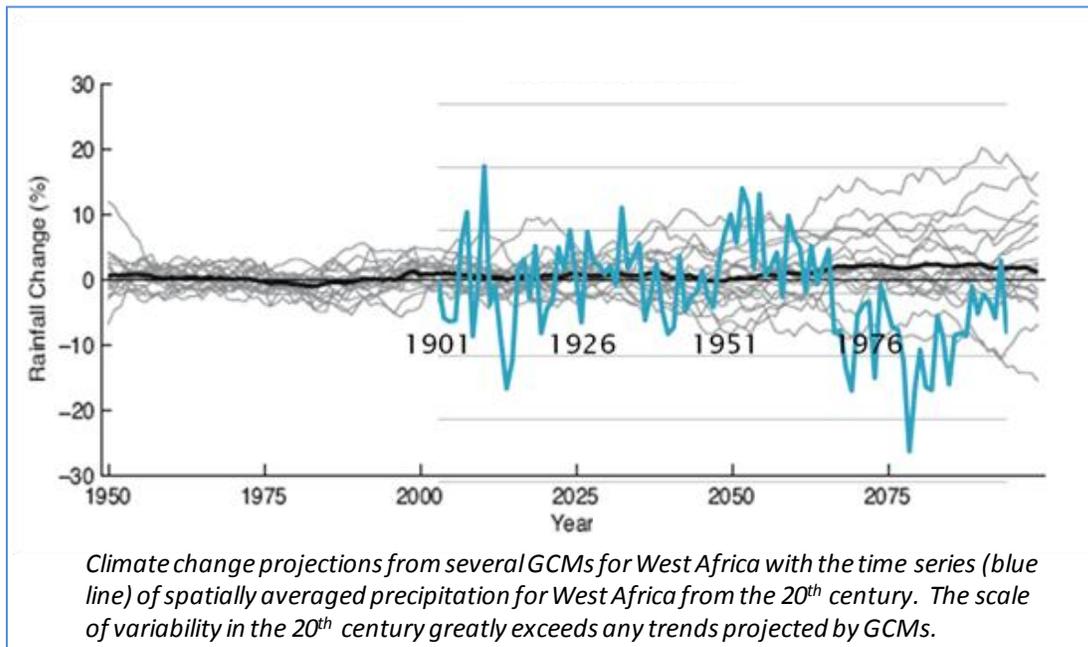
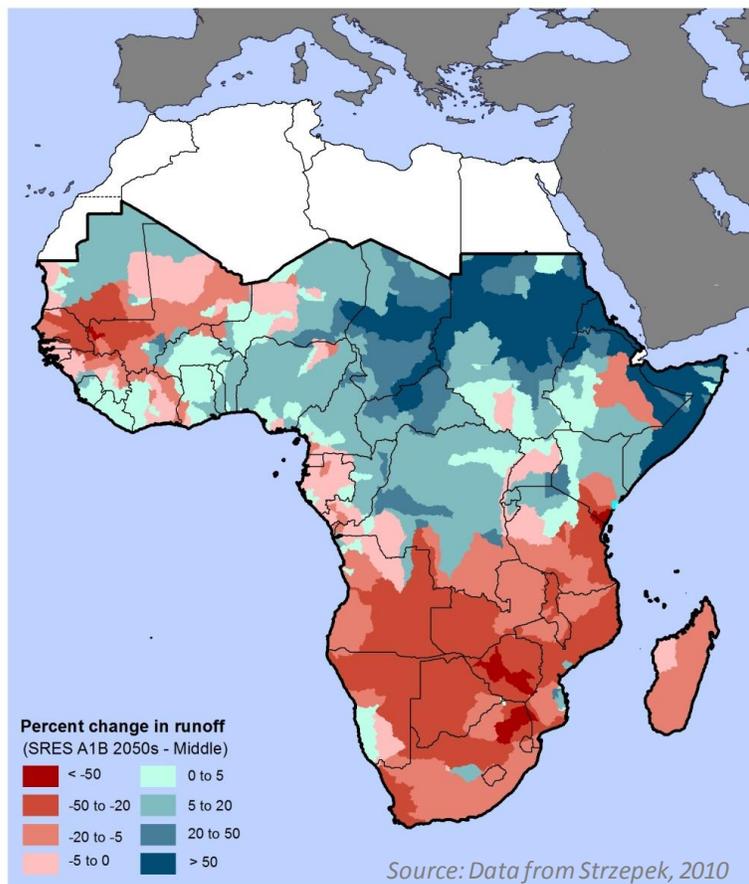


Figure 4.8 Comparison of historical and projected precipitation time series for West Africa

**Runoff changes are even more difficult to compute** because they are governed by both precipitation and temperature changes, as well as land use, land cover and soil types. Initial estimates (Milly et al. 2005) indicate that although the average runoff for Africa may drop only 1 percent relative to twentieth-century averages, regional variability would be substantial. Figure 4.9 illustrates that runoff is projected to decrease in southern Africa, generally increase in central and east Africa and both increase and decrease over the West Africa region. These projections (McCluskey 2011) are based on a simple physical hydrologic model for each of the 670 sub-basins considered in Africa coupled with GCM projections for temperature and precipitation (under scenario A1B in 2050). It is also important to move away from looking only at “blue water” that ends up in a stream or river and focus also on the substantial “green water” that is used in catchments in order to better manage water resources in the basin context.



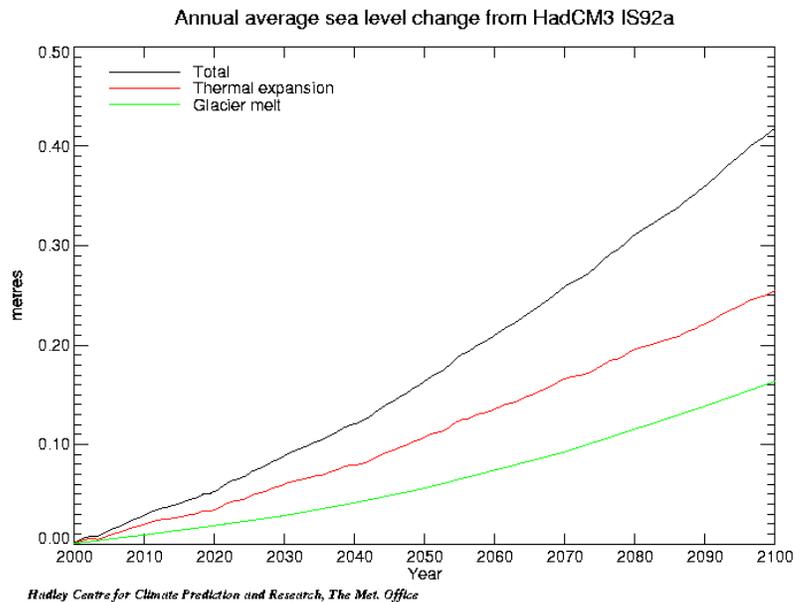
**Overall in Africa, in general the wetter regions are projected to get wetter and the drier regions to get drier (figure 4.9) if we use a “middle” projection.** However, such projections of precipitation and runoff should be treated with caution in operational uses. It is difficult to rank models by confidence. Some have tried to do so by seeing how well they perform in “predicting” the past, but this does not guarantee that they will perform better in the future. At present, all model results are assumed to be equally possible and hence it is difficult to identify which individual projection to use for further analysis.

**All these complexities make it unreasonable to rely on individual climate change models or scenarios when making critical investment decisions.**

**Figure 4.9 Possible runoff changes in Africa**

It is much more reasonable to consider the entire ensemble of results until the time when competing model results converge or one model is shown to be superior to others. At present, given the divergence of model outputs and the many “known unknowns” and “unknown unknowns,” the most prudent approach may be to do a better job at addressing the high level of uncertainty and variability revealed by the historical record.

**Sea levels are projected to rise steadily.** Using a mid-range scenario from IPCC's scenarios, a rise in sea level of 18 to 59 cm can be projected in the next century (figure 4.10). Some researchers have indicated that recent trends (e.g. accelerated Arctic ice melting could result in an ice-free Arctic ocean during the summers within the next decade) could signal an accelerated melting of ice of polar landmasses that could significantly raise these estimates. Such a rise would significantly affect Africa's coasts, deltas, and islands and could have severe effects on coastal ecosystems and communities.



**Figure 4.10** Sea levels are expected to rise  
**Data Source: Hadley Centre for Climate Prediction and Research**

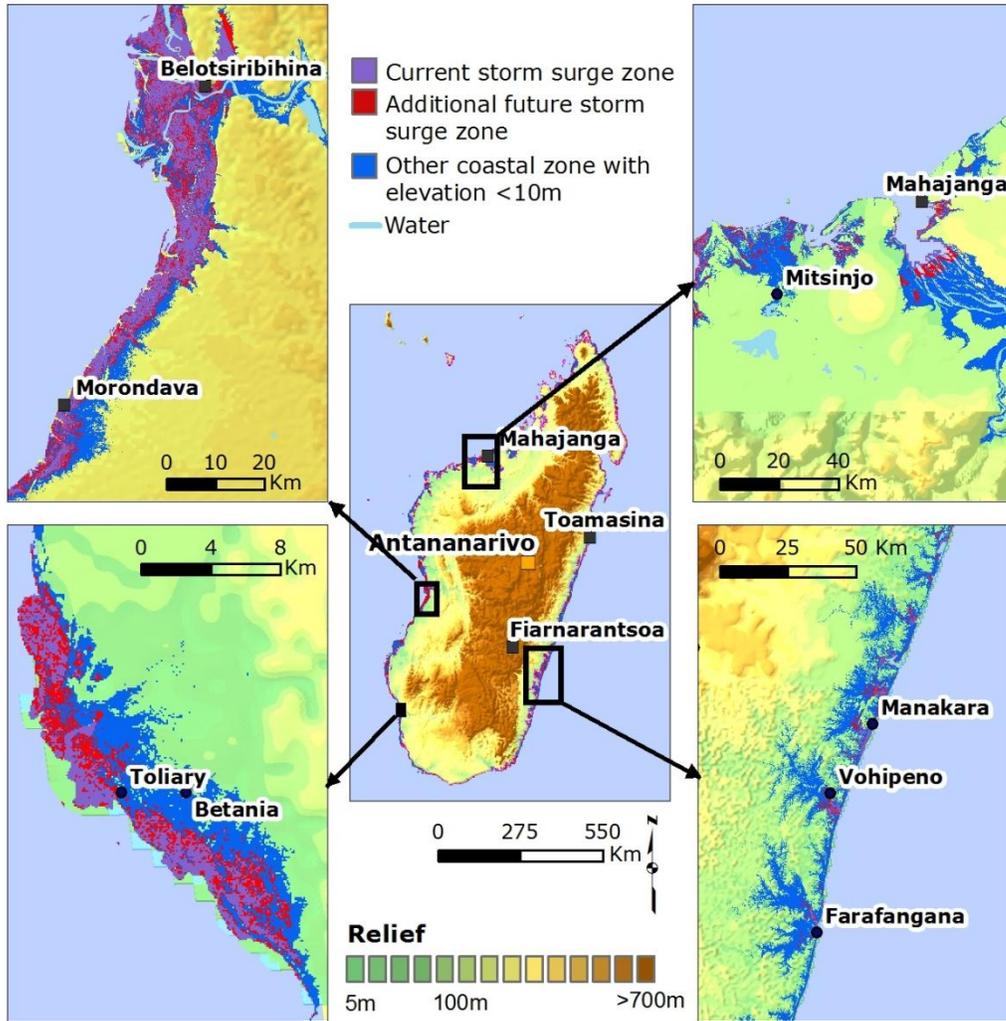
Impacts will occur on both urban and rural settlements along the coast and will affect housing, infrastructure, and other economic assets. The impacts are not only the result of slow submergence of low-lying coastal areas to rising sea levels, but also the compound effect of coastal storms that would now reach further inland with a higher sea level, especially during high tides. The effects are expected to be exacerbated by subsidence of delta land, degradation of coastal wetlands, and losses of coral reefs.

More than a quarter of Africa's population lives within 100 km of the coast. If the sea level rises by one meter or more (near the higher end of the IPCC projections), the impact (both direct and from greater storm surges) would be very serious in several African countries. For example, figure 4.11 indicates the vulnerability of selected coastal areas in Madagascar to sea level rise and storm surges. A recent World Bank study (Dasgupta et al. 2007) reviews new data on rates of deglaciation in Greenland and Antarctica and projects that the rise in sea level will be two to five times greater than the IPCC estimates. If these more extreme scenarios were to come about, The Gambia and, to a lesser extent, Guinea-Bissau, would be the most heavily affected countries in Sub-Saharan Africa.

**Extreme weather events could increase.** Some scientists also predict a change in extreme weather events, with stronger and more frequent cyclones and stronger summer monsoons owing to changes in ocean heat and water vapor.<sup>2</sup> Sea-level rise would magnify the impacts of such cyclones, with floods from higher storm surges and strong winds increasing the vulnerability of low-lying coastal settlements. Climate models have not yet incorporated such phenomena or made precise predictions about them; however, they could prove to be "tipping points" that have large, discontinuous impacts on growth and livelihoods. This is especially problematic for countries such as Madagascar and Mozambique that currently bear the brunt of most of the coastal storms in Africa (see figure 3.10).

<sup>2</sup> [http://www.ucsusa.org/global\\_warming/science/hurricanes-and-climate-change.html](http://www.ucsusa.org/global_warming/science/hurricanes-and-climate-change.html)

## MADAGASCAR Sea Level Rise / Storm Surge Vulnerability



Source: Based on data from various sources - Sea storm surge (WB, 2010), elevation model (Hole-filled seamless SRTM data V4, CIAT, 2008).

Figure 4.11 Some coastal areas in Africa are very vulnerable to impacts of sea level rise

## Chapter 5: Development Implications for Water Resources

- It is difficult to plan, especially for the future!
- Climate change may have significant ramifications on Africa's development, especially due to its impacts on the constructive and destructive roles of water.
- In addition to climate change, many other variables need to be considered by water resources planners.

**Water resources are developed in Africa often in the absence of basin-wide planning tools such as models or decision support systems.** Therefore, the consideration of climate change in decision making about investments in a basin context is even more difficult. The evolution of such tools and supporting decision-making institutional arrangements are often a critical pre-requisite for effective water resources planning that takes into account climate risks (historical variability and climate change).

**Climate change may affect large regions of Africa.** Often the potential effects of climate change are described in mean or median terms in an attempt to synthesize General Circulation Model (GCM) outputs. Although this may help simplify communication, it is insufficient for effective planning. Relevant data should be taken into consideration in all their complexity. As explained in the previous chapter, it is necessary to analyze the ensemble of projections to fully understand the existing knowledge on future climate. Any one of these projections will have complex variations in its time series projection.

**Table 5.1 Regional averages of temperature and precipitation for Africa**

2080–99 compared with 1980–99 <sup>1,2</sup>														
Region <sup>3</sup>	Season <sup>4</sup>	Temperature response (°C)					Precipitation response (%)					Extreme seasons (%) <sup>5</sup>		
		Min	25	50	75	Max	Min	25	50	75	Max	Warm	Wet	Dry
West Africa	DJF	2.3	2.7	3.0	3.5	4.6	-16	-2	6	13	23	100	21	4(-)
	MAM	1.7	2.8	3.5	3.6	4.8	-11	-7	-3	5	11	100		
	JJA	1.5	2.7	3.2	3.7	4.7	-18	-2	2	7	16	100	19	
	SON	1.9	2.5	3.3	3.7	4.7	-12	0	1	10	15	100	15	
	Annual	1.8	2.7	3.3	3.6	4.7	-9	-2	2	7	13	100	22	
East Africa	DJF	2.0	2.6	3.1	3.4	4.2	-3	6	13	16	33	100	25	1(-)
	MAM	1.7	2.7	3.2	3.5	4.5	-9	2	6	9	20	100	15	4(-)
	JJA	1.6	2.7	3.4	3.6	4.3	-18	-2	4	7	16	100		
	SON	1.9	2.6	3.1	3.6	4.3	-10	3	7	13	38	100	21	3(-)
	Annual	1.8	2.5	3.2	3.4	4.3	-3	2	7	11	25	100	30	1(-)
Southern Africa	DJF	1.8	2.7	3.1	3.4	4.7	-6	-3	0	5	10	100	11	
	MAM	1.7	2.9	3.1	3.8	4.7	-25	-8	0	4	12	98		
	JJA	1.9	3.0	3.4	3.6	4.8	-43	-27	-23	-7	-3	100	1(-)	23(-)
	SON	2.1	3.0	3.7	4.0	5.0	-43	-20	-13	-8	3	100	1(-)	20(-)
	Annual	1.9	2.9	3.4	3.7	4.8	-12	-9	-4	2	6	100	4(-)	13(-)

1. Based on 21 GCMs for SRES scenario A1B.

2. Table shows the minimum, maximum, median (50%), and 25 and 75% quartile values among the 21 GCM models of the temperature (°C) and precipitation (%) difference between 2080–99 and 1980–99. The differences are based on the average for each model over all available simulations of the historical 1980–99 period and the averages of each model projection for the period 2080–99. Regions for which the middle half (25–75%) of the distribution are all of the same sign are shaded orange (decrease) and blue (increase).

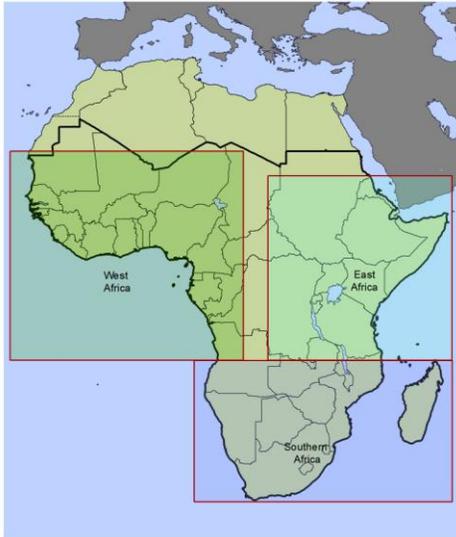
3. A rectangular box with the latitude and longitude of the lower left corner and upper right corner defined as follows: West Africa (12°S, 20°W to 22°N, 18°E); East Africa (12°S, 22°E to 18°N, 52°E); southern Africa (35°S, 10°E to 12°S, 52°E); Sahara (18°N, 20°E to 30°N, 65°E).

4. The seasons are: December, January, February (DJF); March, April, May (MAM); June, July, August (JJA); September, October, November (SON).

5. Numbers in the extreme season columns indicate the change in frequency of extremes based on a reference value whose frequency is 5%, or 1 in 20, computed from the 1980–99 period.

Source: After IPCC Working Group I 2007, chapter 11; see also Müller 2009.

For example, table 5.1 summarizes the long-term temperature and precipitation projections for the period 2080–99 and compares these with historical data for 1980–99 across three major regions of Africa (see figure 5.1). In other words, the table compares the “average” value of each GCM simulation for the 20-year period at the end of the 20th century (1980–99) with the “average” value of the GCM projection for the 20-year period at the end of the 21st century. The distribution of the average values of each of the 21 GCM projections under the A1B SRES scenario was used to compute the values shown to serve as an illustration of how one projection could be used. The table shows that all of Africa will be much hotter; East Africa will be wetter, while southern Africa will be drier between June and November.



**Figure 5.1** Regions of Sub-Saharan Africa referenced in Table 5.1

**Projections of precipitation change in West Africa are highly uncertain.** The pattern of projected temperature change, as shown in the table, is roughly the same across the three regions; approximately half of the projections fall in the range of 2.7°C to 3.6°C, with a median value of about 3.3°C.

**As expected, the projected change in precipitation is much more uncertain than that for temperature,** with a much wider distribution of values. In West Africa, the median projection is a slight average seasonal increase of about 1.6 percent, but half of the model projections range from an average of -2.6 percent to an average of 8.4 percent. The situation is different in East Africa—half the model projections around the median have the same sign—suggesting that there is a high likelihood that this region will become wetter in three of the four seasons (see the cells shaded blue in the table). In Southern Africa the situation is similar except that the projections indicate a strong decrease in precipitation (the cells shaded orange in the table) in the period June to November.

Table 5.1 also summarizes the change in the frequency of extreme seasons defined as warmer, wetter, and dryer than the most extreme case in the 20-year (5 percent frequency) historical control period (1980–99), as simulated by at least 14 of the 21 GCMs. All models project warmer seasons across all three regions. The annual frequency of wet seasons exceeding the wettest season in the 20-year period 1980–99 is about 22 percent in West Africa and 30 percent in East Africa. The models project a decrease in extreme wet seasons in southern Africa, with the exception of December, January, and February (an increase of 11 percent), and a decrease in the frequency of extreme dry seasons in the period June to November.

**Table 5.2 Indicative country climate hazard thresholds**

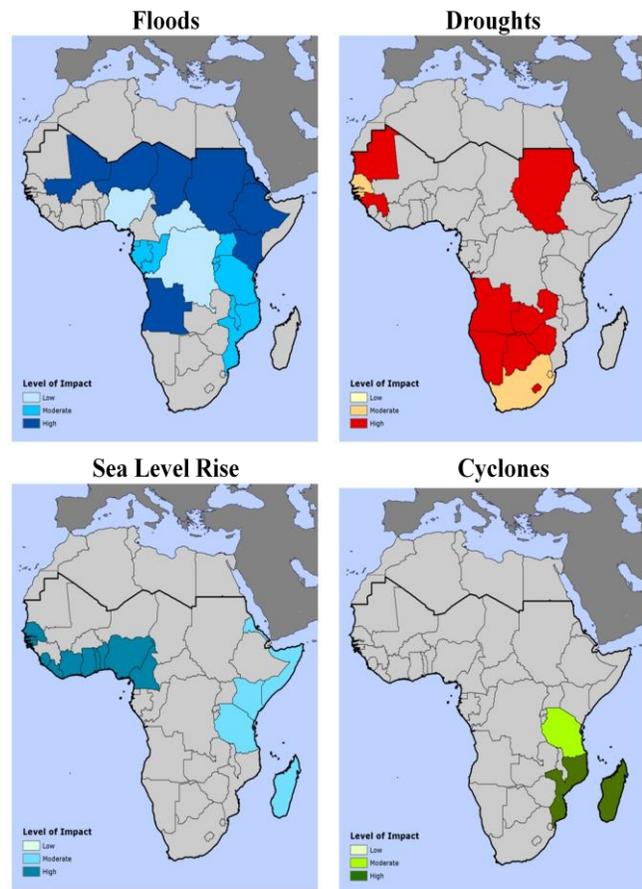
Country climate hazard thresholds			
Hazard	Indicator	Threshold	
		Moderate	High
Precipitation	$\Delta P$ (%) >	7.0	10.0
Temperature	$\Delta T$ (C°) >	1.5	2.0
Drought hazard	$\Delta$ Dry season P	Dec	Dec
	$\Delta$ Runoff	Dec	Dec
	$\Delta$ Inc in consecutive dry days >	5.0	7.0
Flood hazard	$\Delta$ Rainy season P	Inc	Inc
	$\Delta$ Runoff	Inc	Inc
	$\Delta$ Short duration P (%) >	7.0	10.0
	$\Delta$ Dry season P	Inc	Inc

**Many countries could be at risk of extreme climate change.** Figure 5.2 focuses on the distribution of climate change hazards by country and in a smaller time frame: 2030–50 compared with the same historical base, 1980–99. This time frame is particularly helpful when considering projects with shorter economic lives. The underlying data consists of 8 GCMs (11 in the case of precipitation)<sup>3</sup> and the SRES scenario A1B. In addition to the change in mean annual temperature (°C) and change in

mean annual precipitation (%), the number of consecutive dry days and the maximum annual 5-day rainfall were also calculated from the GCM time series and used to construct these maps. Changes in runoff are based on Milly et al. (2005). The relative hazard depicted in the figure is based on projected changes that cross a given threshold, as outlined in table 5.2.

These thresholds are arbitrary and used to indicate countries where the largest hazards might occur by 2040 (the mid-point of 2030–50), about 30 years into the future (see the maps in figure 5.2).

Several other studies demonstrate the relative impacts of climate change in countries across Africa. The studies by Cline (2007) and the World Bank’s Economics of Adaptation to Climate Change (EACC) (2010c) are probably the most recent and comprehensive analyses of the impact of global warming on agricultural productivity. Cline’s methodology combines climate models used by the IPCC with crop models and Ricardian models for more than 100 countries, regions, and subregions. The results indicate that the impact will be greatest in Sub-Saharan Africa. Cline estimates that agricultural output will decline by 28 percent by 2080 without carbon fertilization (figure 5.3). These results are considered to be conservative, since other effects that are likely to accompany climate change—such as pest infestations, severe droughts, and insufficient

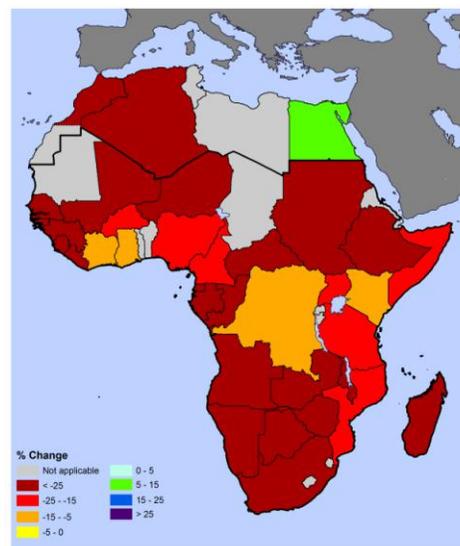


**Figure 5.2 Countries prone to various types of climate risks**

<sup>3</sup> The percentage of models that agree on the sign of change averages about 66% ranging from 55 to 82%

water for irrigation—are not explicitly included. The reduction would be significant across the African continent; most countries would suffer productivity losses of more than 25 percent. Such losses are projected to be acute in the Sahel, the Horn of Africa, and East and south-west Africa—areas that are projected to experience significant decreases in precipitation alongside increases in temperature.

The World Bank carried out farm surveys in Africa (Kurukulasuriya et al. 2006) to examine the relationship between agricultural productivity and climate. This includes analysis of the impact of seasonal temperature and precipitation on net revenues per hectare. The study estimates that climate change would lead to an average decline of 30 percent of net revenues per hectare across all African countries. Significant losses are expected, even in irrigated agriculture. For dry-land agriculture the consequences are even more severe, with a complete shutdown in five countries and regions (Sudan, Horn of Africa, Mali, Niger, and Senegal). All such results need to be considered with caution, however, as they tend to hinge on summarizing the GCM outputs in simplified (that is, median, low/medium/high) metrics that may not capture the uncertainty involved.



**Figure 5.3 Impact of climate change on agricultural productivity (without carbon fertilization)**

Source: Data from Cline 2007.

***Africa has a long, vulnerable coastline that includes about 29 countries.*** Very little research is available to assess the hazard represented by a rising sea level and storm surges on coastal communities, land, and infrastructure. Table 5.3 summarizes recent studies carried out by Dasgupta et al. (2009) of how a rise in sea level of 1 meter coupled with a 100 year storm surge (a storm surge with a 1 percent chance of being equaled or exceeded—a common level of risk in infrastructure design) might impact the coastal zones of African countries. The 29 countries listed in table 5.3 can expect to have some part of their coastal land area or coastal zone affected by both a rise in sea level and storm surges. Four measures of impact are shown in the table: percent of land area, percent of coastal population (and numbers of people), percent of coastal urban extent, and percent of wetlands affected. The shaded values are those impact values that equal or exceed 40 percent.

**Table 5.3 Impact of a rise in sea level and storm surges on coastal areas**

Country	A rise in sea level (1 m) and storm surge (100-year high)				
	% of total coastal land area affected	% of coastal population affected	Coastal population affected	% of coastal urban extent affected	% of coastal wetlands (all types) affected
	(%)	(%)	(#)	(%)	(%)
Angola	29.1	45.8	72,448	46.2	14.8
Benin	19.5	39.0	221,029	44.2	21.3
Cameroon	39.6	34.8	57,214	40.4	43.0
Congo, Dem. Rep. of	17.3	7.6	1,812	31.6	23.3
Congo, Rep. of	15.3	22.1	10,361	21.2	10.7
Côte d'Ivoire	29.2	48.4	315,609	53.2	38.1
Djibouti	38.0	60.1	28,559	60.4	19.3
Equatorial Guinea	17.3	38.5	892	52.6	8.5
Eritrea	32.2	31.2	8,238	42.9	31.8
Gabon	25.6	28.4	34,500	30.4	27.3
Gambia	4.4	40.0	47,233	23.9	4.2
Ghana	39.2	49.2	137,206	48.5	47.8
Guinea	58.6	43.7	58,967	33.3	62.2
Guinea Bissau	35.7	32.9	61,314	34.1	40.0
Kenya	41.9	40.2	27,453	38.9	52.5
Liberia	26.6	44.6	88,535	43.0	46.3
Madagascar	44.7	42.7	102,439	44.1	51.3
Mauritania	21.4	32.9	149,576	42.7	33.4
Mozambique	41.2	51.7	380,296	55.1	47.1
Namibia	60.2	42.2	957	50.0	81.6
Nigeria	30.9	25.4	870,276	28.5	38.8
São Tomé and Príncipe	44.4	24.0	1053	30.0	0
Senegal	16.5	20.7	190,690	16.1	22.0
Sierra Leone	28.9	34.6	39,080	37.3	33.5
Somalia	28.2	31.0	33,756	25.0	24.8
South Africa	43.1	32.9	48,143	48.1	46.2
Sudan	49.7	49.5	18,762	50.0	58.7
Tanzania	46.7	49.9	75,493	53.4	42.2
Togo	34.2	54.2	147,274	59.8	26.6

Source: Dasgupta et al 2009.

Focusing first on people in the coastal zone (figure 5.4), in 14 of the 29 countries (48 percent) over 40 percent of the coastal population (over 44 percent of the total estimated coastal population of Sub-Saharan Africa) would be adversely impacted (if the threshold is lowered to 30 percent, over half the countries would be impacted). In 17 of the 29 countries (about 59 percent) over 40 percent of the estimated urban area would be adversely impacted (in a similar way, if the threshold is lowered to 30 percent, nearly 60 percent of the countries would be impacted).

These impacts are potentially quite large, not only in human terms, but also in economic and financial terms. Important economic assets—including transport, port and navigation facilities, marine fisheries, and export-oriented industries—tend to be concentrated in urbanized areas in the coastal zone. Coastal wetlands, including estuaries, are also impacted; these typically provide important coastal defenses as well as habitat critical to both marine and inland fisheries. Where urban areas coincide with rivers entering the sea, the affects of a rise in sea level would be compounded during the flood season, causing a backwater effect in the river and increasing flood height. An example from Mozambique in figure 5.5 shows the additional reach of storm surges because of a rise in sea level.

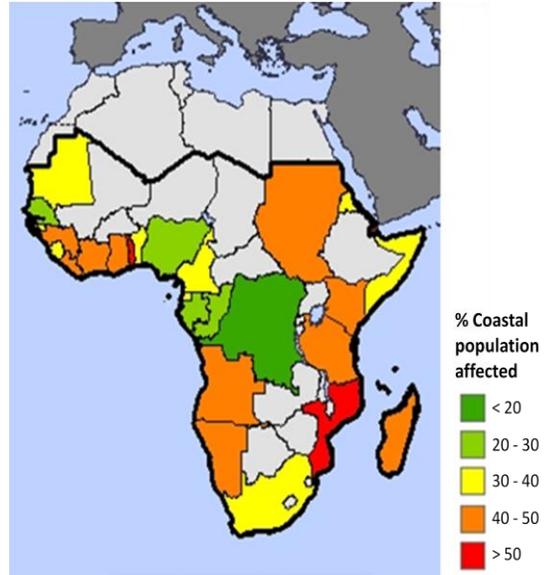
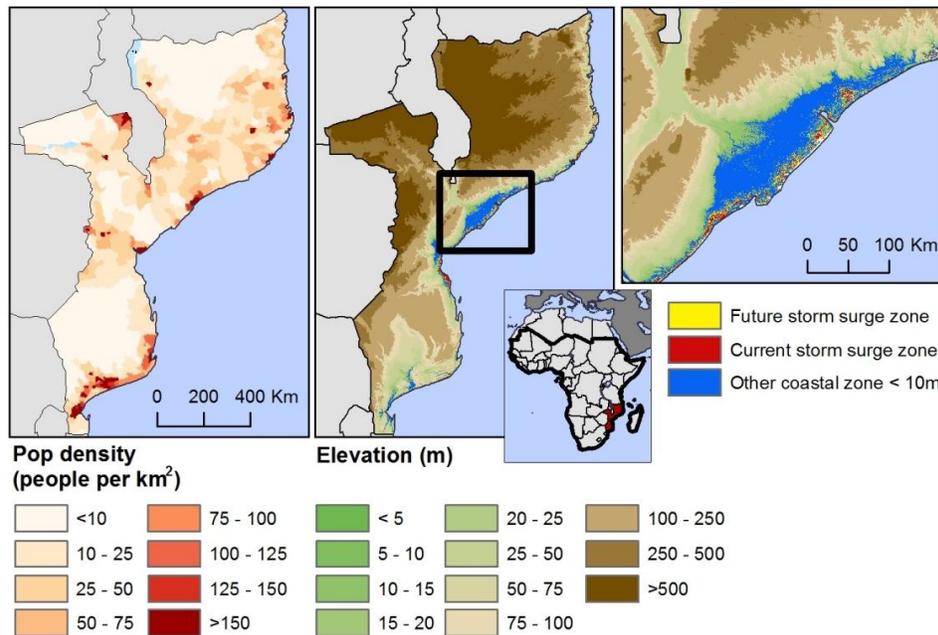


Figure 5.4 Impact of a rise in sea level (1 m) and a storm surge (100-year high) on the coastal population

## Mozambique

### Sea Storm Surge and Sea Level Rise Vulnerability



Source: Based on data from various sources - Sea storm surge (WB, 2010), elevation model (Hole-filled seamless SRTM data V4, CIAT, 2008), and Population density (GPWE-Estimates of human population density for year 2010, 2005, CIESIN-FAO-CIAT)

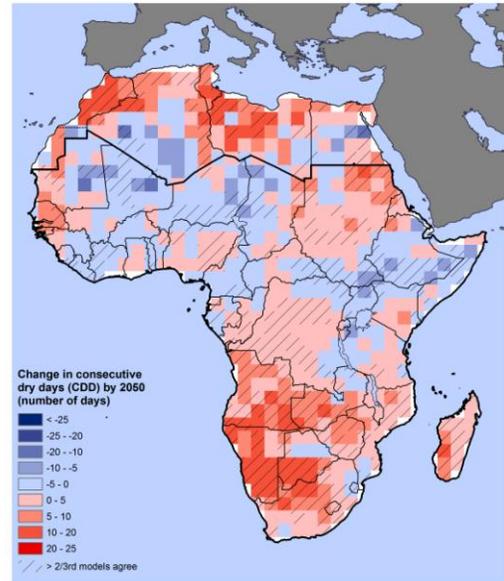
Figure 5.5 An example of storm surge enhancement with sea level rise (Mozambique)

These changes in climate will impact both the constructive and destructive roles that water plays in development. On the destructive front, hydrologic extremes are expected to get worse leading to more drought, flood, and coastal storm impacts (especially in combination with other economic development and population increases). On the constructive front, changes in water supply will impact the availability of water for food, for energy, for people, and for the environment.

### Changes to water's destructive role in development

**Droughts.** The IPCC indicates that drought severity is expected to increase, especially in areas that are already dry. This will have implications for the water and food security of the continent. Figure 5.6 shows the projected change in consecutive dry days by 2050 —indicating that most areas in southern and east Africa are projected to have an increase in the number of consecutive dry days. Alarm at these results needs to be tempered, however, by the knowledge that most models do not agree on projected changes in precipitation across Africa.

**Floods.** In areas where rainfall intensity and duration is expected to increase (although models are usually not in agreement), flood risks could worsen—for example, in areas that are already flood prone—implying quicker return periods for flood flows (that is, a 1-in-a-100-year flood today could, under a “climate-changed” hydrology, be a 1-in-50-year flood or a 1-in-20-year flood depending on how the climate changes). Given the uncertainty in the climate model results, however, it is difficult to accurately predict such changes in advance.



**Figure 5.6 Projected change in consecutive dry days by 2050 (number of days)**

Historical variability signals should be thoroughly analyzed. Most places in Africa have not yet coped satisfactorily with historical climate variability (that is, floods and droughts). It is important for climate researchers and hydrologists to work closely with the development community to better understand the development implications of hydrologic variability and find ways to buffer the impacts of these hydrologic “blips.”

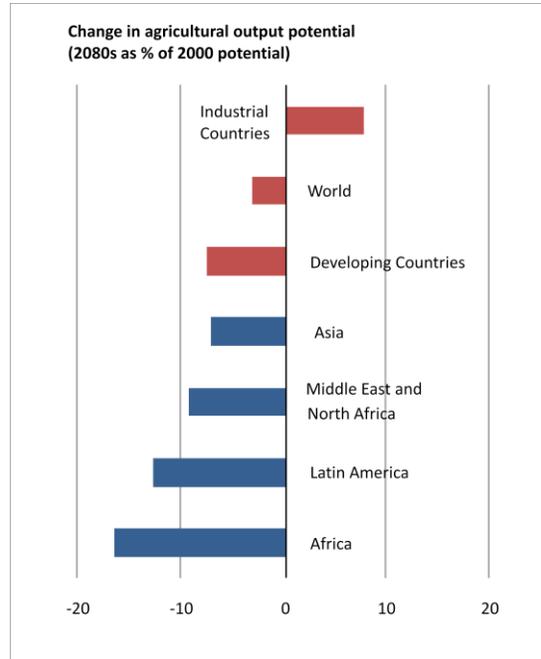
### Changes to water's constructive role in development

#### Water for food

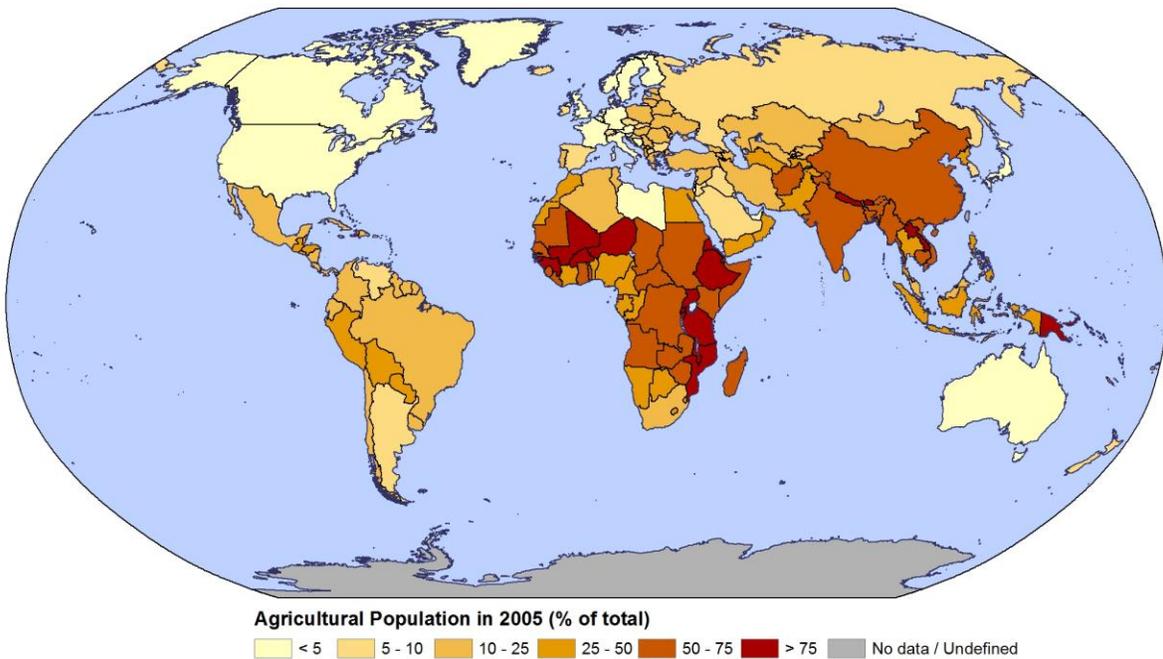
**Food production in Africa may be significantly impacted by climate change (figure 5.7).** Agriculture in Africa accounts for a large share of GDP and a majority of the continent's livelihoods (see figure 5.8). Since over 95 percent of Africa's agriculture is rain fed, agricultural production and access to food in many African countries and subregions are projected to be severely compromised by climate variability. In some countries, yields from rain-fed agriculture could be reduced by up to 50 percent by 2020, and climate variability could aggravate current natural resource challenges and constraints such as poor soil fertility, pests, crop disease, and lack of access to inputs. It could also prove a burden (or opportunity in some cases) for food imports when local production is impacted. Food productivity in Africa may also decrease as the geographical boundaries of agro-ecosystems change due to climate changes which will affect the range of agricultural pests.

**Water demands are expected to increase in agriculture**—crop water requirements are expected to be higher for both rain-fed and irrigated crops as temperatures rise, further exacerbating hydrologic variability. Other demands for water (for example, cooling) may also rise with rising temperatures.

**Repeated droughts and floods** can also take their toll (for example, as lands degrade or infrastructure for food transport and storage is damaged by floods). African countries whose economies rely heavily on one or two agricultural cash crops are particularly vulnerable to **uncertain climate change**.



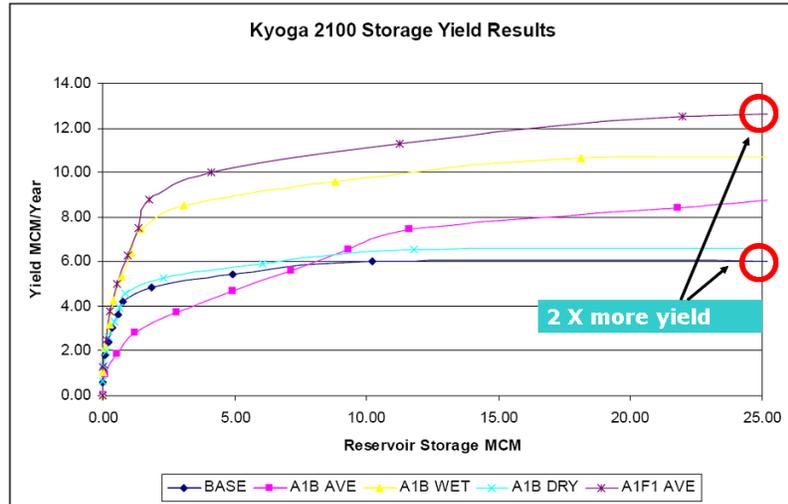
**Figure 5.7 Projected changes in agricultural output potential in different areas**  
Source: Cline 2007



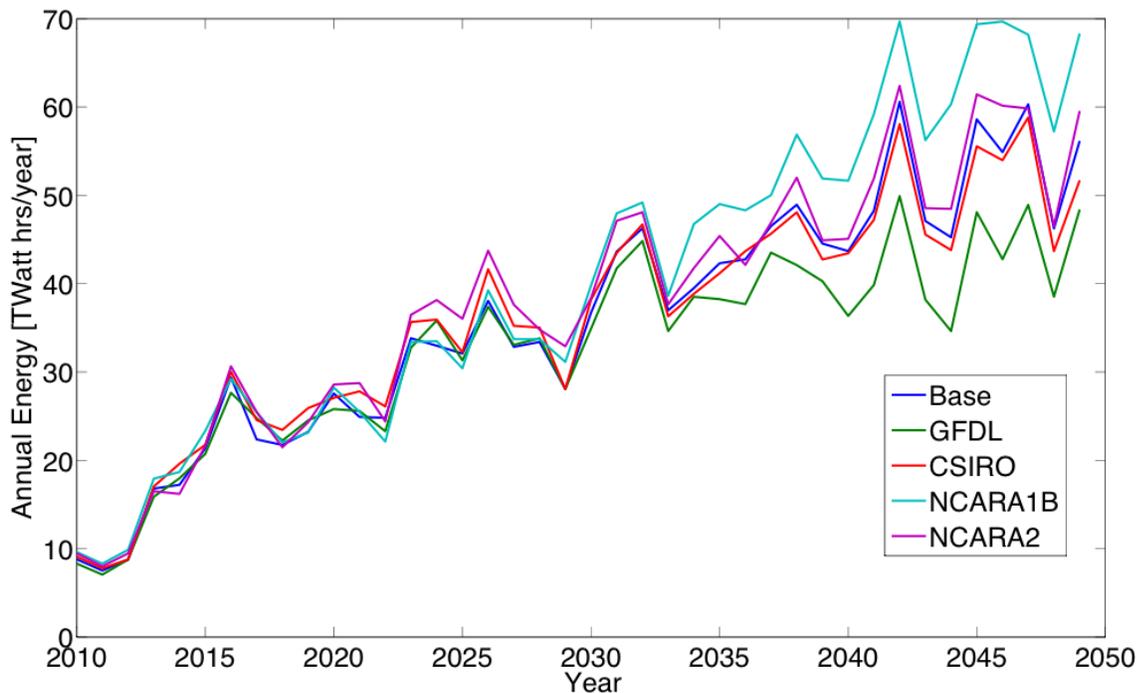
**Figure 5.8 Percentage of the country population with livelihoods dependent on agriculture**

**Water for energy**

**Hydrologic changes will impact hydropower generation.** This could be in quite complex ways. Reduction in flows could impact generation at run-of-river or even storage-backed hydropower plants. The threat of increased flood flows (exacerbated by accompanying fears of increased erosion) may force the conservative operation of hydropower plants at lower storage levels, resulting in suboptimal power generation. There may be occasions where the expected climate changes indicate benefits—as shown by figure 5.9 - that considered the possible impacts of climate change on proposed hydropower infrastructure alternatives in a sub-basin of the Nile. Similarly, figure 5.10 shows the projected hydropower generation in Ethiopia under a variety of GCM scenarios on top of a projected development paradigm. We see that there could be significant changes in hydropower, especially in later years, depending on the GCM used—however, it is difficult to define the range of impacts using this sensitivity analysis.



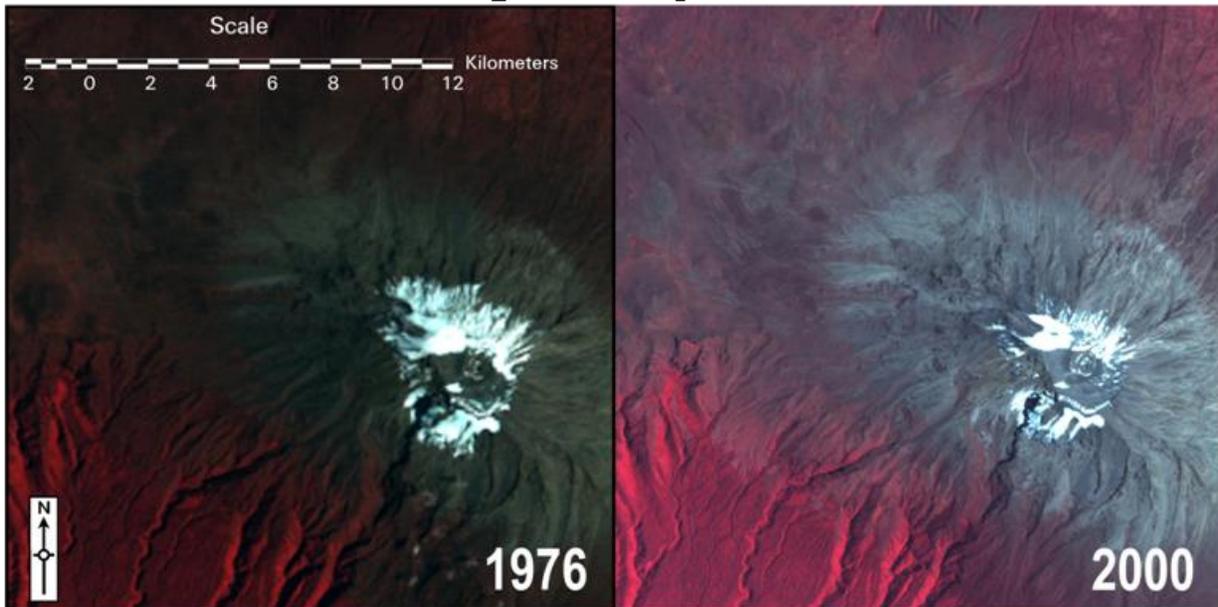
**Figure 5.9 Storage-yield scenarios under various SRES scenarios**  
 Source: Strategic Social and Environmental Assessment for the Nile Equatorial Lakes Region



**Figure 5.10 Possible hydropower impacts on Ethiopian hydropower generation under four GCMs**  
 Source: World Bank 2010d



## The Melting Kilimanjaro Glacier



*Source: Based on data from 1976 image (24 January 1976, Landsat 2 MSS bands 4, 5, 7) and 2000 image (21 February 2000, Landsat 7 ETM+ bands 4, 3, 2), downloaded from GLOVIS (<http://glovis.usgs.gov/>)*

**Figure 5.12** The spatial extent of Mt Kilimanjaro glacier in 1976 and in 2000

### Summing up

The fourth assessment report of IPCC, released in 2007, indicates the following implications of climate change for Africa:

- By 2020 between 75 and 250 million people are projected to be exposed to increased water stress due to climate change.
- By 2020 yields from rain-fed agriculture could be reduced by up to 50 percent in some countries. Agricultural production, including access to food, is projected to be severely compromised in many African countries. This would adversely affect food security and exacerbate malnutrition.
- Toward the end of the 21st century, a projected rise in sea level will affect low-lying coastal areas with large populations.
- The cost of adaptation could amount to at least 5–10 percent of GDP.
- By 2080 arid and semiarid land in Africa is projected to increase by 5–8 percent under a range of climate scenarios.

Many of these implications are related to water, and none bodes well for Africa's development. The dimensions of sustainability—economic, social, and environmental—will all be impacted. The cascade impacts of climate change are expected to vary significantly depending on the magnitude of changes in climatic factors such as temperature, precipitation, and sea level—superimposed on existing physical, environmental, and socioeconomic conditions.

***There is a need to overcome “climate resilience deficits” in coping with existing historic climate variability and move to coping with additional climate change risks. However, climate change is not the only determinant for water planning. “Development deficits,” in terms of the need to provide services for a growing and increasingly affluent population are the primary determining factor for water planning.*** Water-related investments are planned to deliver livelihood and economic growth benefits to growing populations. In future, the key determinants of water-related investments will continue to be population increase, economic growth (with income effects on water-related services), and increasing urbanization/industrialization (changing the distribution/type of water investments). These pressures promise to stimulate investments in the provision of basic water, hydropower, and agricultural services to catch up with historical development deficits. This would further stress water resources, especially in already stressed areas (for example, over-pumping groundwater in coastal aquifers, increasing competition for water, and polluting surface and ground waters, rendering them expensive to utilize or clean up—as has been the case in many other rapidly urbanizing and industrializing parts of the world). Overall development trends and uncertainties (largely driven by current status, location, governance, infrastructure, services, education, and attractiveness to private sector and development partner investments) will probably have the most influence on the choice and design of water-related investments.

As we will see in chapter 6, we need a new approach in order to go beyond generalities to determine adaptation strategies for specific water systems combining both development and climate scenarios.

## Chapter 6: Climate Risk Assessment

- A climate risk assessment means different things to different people.
- Indicators of system performance and vulnerability and a system modeling framework are critical to a climate risk assessment.
- The Climate Risk Assessment methodology offers a way to undertake the “climate screening” of investments or investment plans.

Climate risk assessment (CRA) means different things to different people. An attempt is made here to present it in a comprehensive manner that takes into account both historic climate variability and future climate change. First it is necessary to define several key terms (box 6.1).

### Box 6.1 Definitions of key terms

*Perturbation:* A systemic disturbance resulting from a sudden shock of a magnitude beyond “normal” vulnerability.

*Hazard:* The threat of a stress or perturbation to a system’s values (e.g. lives, livelihoods).

*Stress:* Cumulative pressure on a system resulting from processes within the normal range of variability, but which over time may result in disturbances that either harm a system or otherwise move it to adjust and adapt.

*Exposure:* The contact between a system and a perturbation or stress.

*Sensitivity:* The extent to which a system or its components is likely to experience harm—and the magnitude of that harm—due to exposure to perturbation or stress.

*Vulnerability:* The degree to which a person, system, or unit is likely to experience harm due to exposure to perturbation or stress.

*Risk:* The conditional probability and magnitude of harm attendant on exposure to a perturbation or stress.

*Resilience:* The ability of a system to absorb perturbation or stress without changes to its fundamental structure or function that would drive the system into a different state (or to extinction).

*Robustness:* The ability of a system to perform satisfactorily under a wide range of scenarios.

*Adjustment:* A systemic response to perturbation or stress that does not fundamentally alter the system itself.

Adjustments are commonly (but not necessarily) short term and involve relatively minor system modifications.

*Adaptation:* A system response to a perturbation or stress that is sufficiently fundamental to alter the system itself, sometimes shifting the system to a new state.

*Source:* Based on Turner et al. 2003.

Some of these definitions are operationally relevant. For example, a flood event is a *hazard*, but unless there is *exposure* of the population to the flood, their *vulnerability* to the flood is low. The *risk* will then depend on how big the flood is and the vulnerability of the population to it. The *adaptation* to this may involve hardware (structural) measures such as building levees/ embankments along a river’s banks, or software (nonstructural) approaches such as flood early-warning systems. Such measures reduce the risk by reducing either the degree of the hazard or the exposure of the population to it.

A summary of a CRA methodology was presented in chapter 1 (figure 1.3). A CRA assessment, done systematically, may include a critical analysis of *information*, *institutional*, and *infrastructure* aspects (figure 6.1).

The key steps to follow in a comprehensive climate risk assessment are described below:

**(a) Current situation**

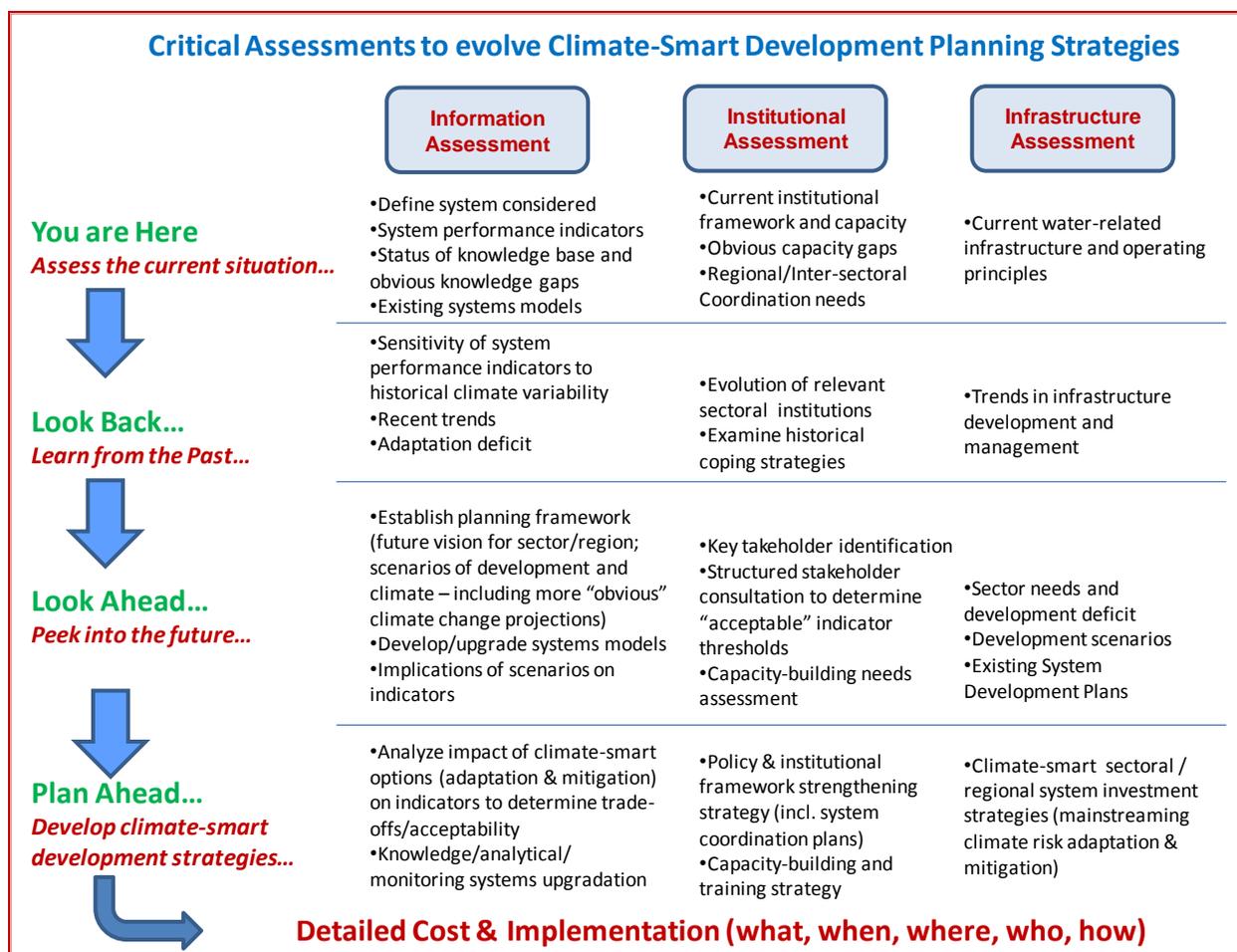
First, it is important to gauge the spatial setting, knowledge base and analytical tools, institutional capacity available to address climate issues, and existing infrastructure (for example, in the case of a key regional basin). This information will guide the rest of the CRA process.

The system chosen is critical. It could be just one investment (for example, a dam); some insight can be gained by examining a particular investment in isolation. That said, it is often important to examine the investment in the context of a larger system—such as a basin or sub-basin—in order to internalize externalities. For example, the context of a large dam (catchment areas, other upstream and downstream dams and diversions, and so on) is essential to consider when analyzing how a piece of infrastructure may function in a system under different development and climate scenarios. It is also essential to keep the system examined at a manageable level, as there are always externalities—for example, hydropower production from the dam will have its own power system, with a power transmission grid and interconnected power plants, or an interbasin diversion will add a whole new basin into the systems context. In such cases, planners will need to determine the level of subsystem complexity to be considered for the decisions to be made. This will of course depend, too, on the level of information available to support the analysis at this stage.

**Table 6.1 Illustrative System Performance Indicators**

Subsystem	System performance indicators
Agriculture— Irrigation	<ul style="list-style-type: none"> <li>▪ Surface Irrigation area</li> <li>▪ Production</li> </ul>
Energy	<ul style="list-style-type: none"> <li>▪ Energy production (total)</li> <li>▪ Energy production (firm)</li> </ul>
Fisheries	<ul style="list-style-type: none"> <li>▪ Production of fish</li> </ul>
Livestock	<ul style="list-style-type: none"> <li>▪ Fodder availability</li> <li>▪ Livestock production</li> </ul>
Water Transport	<ul style="list-style-type: none"> <li>▪ Minimum water volume in selected reaches</li> <li>▪ Number of days of required river water depth</li> </ul>
Health	<ul style="list-style-type: none"> <li>▪ Cases of water-related diseases</li> </ul>
Biodiversity & Ecosystems	<ul style="list-style-type: none"> <li>▪ Minimum environmental flows (in selected stretches and to sea)</li> <li>▪ Number of aquatic species of flora and fauna</li> </ul>

The critical step here is to identify indicators of system performance that could be impacted by climate risks. This needs to be done through an informed, structured stakeholder consultation process to ensure that all key climate-sensitive aspects of a system's performance are taken into account in the form of suitable metrics in order to compare development and climate scenarios. An example is given in table 6.1 (based largely on some of the indicators evolved during a Niger Basin Authority workshop on the Niger Basin work undertaken as part of the application of this framework in this study). Many of these indicators can be modeled, but some (such as species of flora/fauna) require additional studies or expert opinions. The indicators should ideally be those that pass the SMART (Specific, Measurable, Achievable, Relevant, and Time-bound) test.



**Figure 6.1 Proposed climate risk assessment methodology**

### (b) Looking back

As suggested in the previous chapters, it is important to thoroughly review sensitivity to historical climate and hydrologic variability as well as recent trends. In many parts of Sub-Saharan Africa the historical climate coping deficit may be the dominant climate factor affecting water investment design over the next 20 – 30 years. Examination of historical time series of meteorological and hydrological records enable planners to estimate the probability of rainfall/runoff anomalies (departures from average, low, or high conditions), extreme conditions such as droughts (length and magnitude) and floods, and thus to estimate the risk of adverse climate and hydrologic events that cause levels of vulnerability that cross the threshold of acceptable risk.

While the institutional assessment undertaken as a part of the scoping process is primarily intended to provide an institutional baseline, it also enables planners to ask how well the current institutional arrangements and capacities are able to deal with current climate and hydrologic variability and key water management issues that will affect the project, as well as to identify related capacity and policy gaps. Managing climate risk is not done by a single discrete intervention—say, the introduction of an item of infrastructure or a new technology. It is a continuous process requiring the monitoring and adjustment of approaches and of the array of actions used at any point in time. Hence, the institutional framework—capacity, tools, policy framework, and other arrangements—is essential for climate risk

management and should be an important element of a climate-smart strategy with a focus on adaptation.

The trends in the stock of water infrastructure investments and the sensitivity of system performance indicators to historical climate variability will largely determine the development and climate framework for the future scenario analysis in the CRA.

### **(c) Looking ahead**

Chapter 4 suggests that the hydrologic time series we might experience in the future could be fundamentally different from that experienced in the past. True, the statistical properties of the future time series are different from the past—means are shifting up or down and variability is increasing, which suggests that the magnitude and frequency of departures from the average will increase to include more extreme values. Hence, one must find a different method to determine the values of climate and hydrologic variables that cause unacceptable vulnerability. The previous discussions suggest that the first step in approaching this issue is to identify the values of the climate and hydrologic variables that result in unacceptable vulnerability in terms of the chosen indicators and thresholds. These values constitute a hypothetical climate and hydrologic scenario whose likelihood needs to be estimated to gauge the risk the project will face. This can be determined by examining the probability distribution of achievement of the system performance variables (for example, a cumulative distribution function of hydropower generation in gigawatt hours per year under various scenarios).

In general, determining these cause-and-effect relationships requires that we model the water system in the specific spatial context of the project or program, that is, in the catchments and river basin in which it lies. This may also be true for rain-fed agriculture since there is every indication that more intensive water harvesting and the development of supplemental irrigation sources will be important for the future viability of rain-fed agriculture (and “green” and “blue” water concepts can be integrated). As outlined earlier, a hydrologic model is needed to predict runoff and, possibly, groundwater recharge for a range of hypothetical climate scenarios—different values of temperature and rainfall. A water system model is needed to simulate the behavior and operations of the water system for predicted runoff values in order to determine the effects of each scenario on vulnerability. This process enables planners to test the efficacy and effectiveness of adaptation options. There are few, if any, cases where the water-agriculture system can be analyzed in isolation from other activities and water uses in other important sectors, including the environment. Changes in land use, and soil and forest degradation, affect the response of the hydrologic system to climate scenarios, the operation of storage reservoirs for power and water supply, and large-scale abstraction of groundwater for growing urban areas. These are examples of activities in the catchments and river basin of interest that will increase water scarcity and affect the availability and reliability of agricultural water.

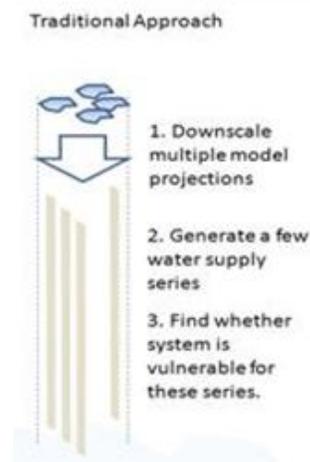
### **(d) Planning ahead**

The next step is to then synthesize the knowledge of climate vulnerability and risks, and find ways to adapt appropriate interventions (here, mitigation options such as afforestation could also be helpful). The impact of these interventions would then need to be analyzed to examine the changes in the severity of the hazard, the vulnerability of people and their livelihoods and infrastructure, and the overall risk. The costs of such interventions can then be traded off against the risk reduction achieved in order to determine the appropriate set of interventions to be implemented.

**The traditional approach to climate risk assessment is flawed.**

For CRA to be effective, it is critical that the implications of historical climate variability are considered in addition to future climate change. Traditionally, one can see many versions of climate change assessment that use either a few GCM outputs directly for one or a few scenarios (or their mean), or downscaled versions of these, in order to obtain possible future naturalized (or “virgin”) stream flows. These are then sometimes analyzed from a systems perspective to determine vulnerabilities.

This traditional approach (figure 6.2) is to first turn to the hazards, in particular to the IPCC AR4 GCM<sup>4</sup> model results, for climate change projections. The projections of change in key climate variables (especially precipitation) from the present to the end of the century are distributed across a very wide band that widens with time into the future (Figure 4.8), and varies as well with which SRES scenario(s) for greenhouse gas emissions are adopted. Moreover, the GCMs and the daily calculations are made on a grid that averages about 3° x 3°, approximately 250 km x 250 km.



**Figure 6.2 The traditional CRA approach is flawed**

To overcome the coarseness of this grid, statistical or dynamical downscaling of the GCM results is carried out—typically only a few GCM time series are downscaled because of the computational burden—or by interpolating the GCM model results onto a finer grid (say 0.5° x 0.5°) so that results are better able to match the spatial characteristics of the project area. In view of the wide divergence of results, mean or median values at particular points in time (commonly decades) are typically used, as well as an analysis of the daily series. The projected daily time series for temperature and precipitation has been limited to calculations of means (seasonal and annual) and extremes (change in maximum number of consecutive dry days, change in maximum five-day rainfall, change in average rainfall intensity [mm per rainy day], and change in heat-wave duration index). With these data in hand we still face the problem of relating these changes directly to vulnerability—that is, of determining what impact they might have. Until now planners have typically relied on intuition and subjective judgment to suppose what may happen to a project, or to key activities within a project, if changes occur (of course, their judgment is most often based on a thorough understanding of the sector). Relying on intuition or judgment is not a sound approach to investment choices but it has other limitations as well:

- There is no way to meaningfully assess the “skill” of the various GCM models, to estimate the statistical properties of the projected time series, or to associate a probability with the values calculated from the time series. The range of estimates is so wide that the calculated means are of little use—there is no way to know which of the GCM time series is more likely than any other (Brown et al. 2010). The wide range of results also makes downscaling often meaningless—they would generate more data but not necessarily provide any additional information or insights.
- At present the GCM models are not good at replicating current climate at spatial and temporal scales that are relevant to agriculture-related water management (and in the cases where they do so, this is not a good indicator of their ability to predict the future); the

<sup>4</sup> AR4 refers to the IPCC Fourth Assessment Report, and GCM refers to the General Circulation Models on which AR4 depends.

models appear to cover temperature reasonably well, but much less so precipitation and even less variability.<sup>5</sup>

- The failure to emulate variability is particularly important in areas subject to frequent drought, or where flood frequency and magnitude are important. The IPCC AR4 report concluded that it is quite likely that variability and extremes may increase in the future. But the nature of the variability is important. For example, should we assume that worse droughts are drier or that they will last longer—say for five years instead of one year?
- The GCMs often do not produce stream flow data sets, so the uncertainty of the projections must be combined with additional modeling and another set of assumptions and approximations.

Whether we need to do anything different or differently, or to introduce some kind of adaptation to reduce impact directly or improve coping capacity because of climate variability or change, depends on how much risk we are willing to accept. The actual vulnerability of a system combined with the probability that the hazard(s) causing that vulnerability might occur is the risk. Estimating risk in project design and implementation—and deciding how much risk to accept—is commonplace. For example, the design of bridges, dam spillways, reservoir capacity, and water supplies for irrigation and drinking water are all examples where risk of failure (lack of service or shortage) is estimated and a level of acceptable risk is determined based on cost or something more catastrophic such as loss of life or damage. These risks are used to decide which investments to make and how much to invest in measures to mitigate these risks. In this sense, an adaptation measure can be thought of as a measure undertaken to mitigate the risks that arise from *changes* in climate, hydrology, and climate variability. In general adaptation measures are not so different from the variable considered in designing a project or program in a specific physical, social, economic, and environmental setting. The difference is that the risks induced by climate or hydrologic change or changes in climate variability may compel planners to *do different things* (perhaps additional) or *to do things differently*—in other words, to change options or their combination to better cope with the new design conditions.

There are two problems with implementing this concept of CRA. First, we do not know the probability that specific climate and hydrologic change hazards will occur (for example, the GCM projections of temperature or precipitation in the future). We know even less about changes in variability (notwithstanding the projections given in table 5.1). There is a high degree of confidence that temperature may increase in parts of West Africa, where temperatures have been increasing over the past century, but the probability that average annual temperature increases—by, say, 1 or 2 or 3 degrees over the next three decades—is not known and cannot be estimated directly at this point in time. While changes in precipitation are also projected to occur, the degree of confidence in estimating them is smaller than is the case for temperature, and the probabilities of their occurrence are much more difficult to estimate. Second, the consequence or impact of a hazard (change in temperature, precipitation, or runoff) is generally location specific and often requires considerable analysis (modeling) to determine. Thus only one or a few GCM runs are typically used in the analysis of vulnerability (this is also the case for the downscaling of GCM results because of the time and computational burden involved), even though one GCM or model run is no more likely to represent the future than any other

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<sup>5</sup> Alavian et al. (2009) make the argument that the so-called cone of uncertainty (the upper and lower bounds on the range of possible future values, for example, of mean seasonal precipitation) narrows considerably as one changes spatial scale from a moderate grid (a 1° square grid at the equator covers an area of about 12,400 km<sup>2</sup>) to the catchment to the river basin to the region. The spatial scale of projects is commonly at or below the grid or catchment scale where uncertainty is highest, although one or more such projects could be part of a (spatially) much larger river basin development plan.

(even among those thought to represent the baseline historical period reasonably well). Kundzewicz and Stakhiv (2010) caution that GCMs are not yet ready for “prime time” in water resource management and related climate adaptation applications as water professionals attempt to often incorrectly use these models that were primarily the domain of climate scientists.

These issues suggest that, in the future, water management and development decisions will be made under conditions of both development and climate uncertainty, using tools with uncertain inputs for climate and hydrologic change. In the case of water, development uncertainty could be reduced by adopting a basin-and-system framework that accounts for potential future patterns of development in other sectors, as well as hydrologic risk. Meanwhile, CRA requires an estimate of the probability that vulnerability thresholds will be crossed.

This can be done with the aid of historical climate data and with inputs from GCMs where there appears to be agreement. In most cases the best guide to climate variability and change risk may be the historical record, since historical extremes (including variability) exceed or are of the same order of magnitude as projected future change. Improved resilience and adaptation to these historical patterns may be the best short-term strategy to cope with possible climate change.

***Based on these factors, we suggest that CRA move from a traditional approach to a “bottom-up” or “decision-scaling” approach that involves three basic steps:***

1. Identify the system’s vulnerability to scenarios of development and historical climate variability.
2. Identify additional vulnerability to obvious climate change parameters (for example, temperature increase, rise in sea level, and snow/glacier dynamics where relevant, given poor model agreement on precipitation and variability changes).
3. Develop climate-smart strategies that address the risks.

Identifying vulnerability requires an understanding of the system and of climate events with problematic impacts. A system model must assess impacts for a range of climate events. To estimate risk requires that we assign probabilities to climate events, largely based on historical climate data. To base these probabilities on multiple climate projections from available GCMs (all of which are considered equally probable) would probably be premature given the level of GCM modeling today and the large uncertainties in many basins.

All the models, however, project increases in temperature (although issues like cloud cover may complicate implications for evapotranspiration, and so on). This climate change information can be used along with development and historical climate scenarios in order to develop additional scenarios to examine the sensitivity of the system performance indicators. It is important that such “robust decision making” in the short-term under conditions of long-term uncertainty requires the systematic consideration of a multiplicity of plausible futures (Lempert, 2003).

***The level of utilization of climate change scenarios also relates to the timing and longevity of interventions.*** It is evident from many GCM runs for Sub-Saharan Africa that substantial climate change begins to appear in the medium to long term, say from around the 2040s or 2050s to 2080–90. The timing question is crucial for investment in infrastructure. Major infrastructure such as large bridges, high-capacity transmission lines, dams and hydropower-generation facilities, and large irrigation diversion headworks are examples of infrastructure whose economic life would typically extend beyond the medium term, say the next 25–30 years, into the long term (2070–80). Despite the uncertainty

inherent in predictions of the magnitude and even the direction (sign) of change, it seems safe to assume that significant change will occur over the long term. Since this change is likely to occur well within the economic life of current infrastructure, the plans and designs for major rehabilitation (or new infrastructure) must account for such change.<sup>6</sup>

Decisions regarding shorter-lived infrastructure—that is, infrastructure whose replacement cycle extends into the medium term, 2040–50—are more problematic since we appear to know less about the near- or medium-term changes. (Examples of shorter-lived infrastructure include earthen water-harvesting structures, large boreholes and wells, and pumping stations). Other issues to be considered are the maintenance burden, and the difficulty and costs associated with adjusting or resizing infrastructure such as canals, bridges, and cross-drainage facilities.

A CRA that uses a hydrologic and water-system simulation model does not break new ground, but it does require data, information management, and modeling skills that are lacking in many countries. The picture in Sub-Saharan Africa, however, looks promising. The NAPAs<sup>7</sup> have spurred the development of capacity and useful tools for climate risk management, particularly the gathering of relevant data and information management using GIS. Programs for river basin management and development can be found in nearly every part of Africa (for example, the Nile, the Okavango, the Niger, the coastal basins in Tanzania, the Zambezi, and the Limpopo), and these planning, data-collection, research, and capacity-building programs have become an important platform for the development of modeling and planning skills.

In effect, a silver lining of the cloud of climate change is an increase in planning for the sustainable development and management of water resources—and an increase in the skills required to do this well.

***This approach is a basis for “climate screening” of water investments; however, it requires customization*** to address various systems and water-using subsectors (such as agricultural water management, hydropower, bulk water supply, and ecosystems), as well as water-related issues (for example, the management of disasters such as floods, droughts, and their effects on groundwater and water storage). To clarify how these variables are integrated in system planning, we use the case of the Niger basin as an example in chapter 7.

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<sup>6</sup> Note that a key adaptation may be in the strategic planning process itself; that is, the specific option or project chosen, while important, may not be as crucial as building options into the plan that over time will accommodate for climate changes by augmenting capacity or seizing new opportunities in a timely manner.

<sup>7</sup> National Adaptation Programs for Action (NAPA), supported and prepared by countries under the UN Framework Convention on Climate Change (UNFCCC).

## Chapter 7: “Climate Smart” Water Planning: A Case Study and Lessons Learned

- *The Niger Basin case provides useful lessons on how to practically apply the Climate Risk Assessment methodology proposed in this study.*
- *Climate-smart development is based on choosing interventions from among the “three I’s”—information, institutions, and investments—with an eye toward adapting to and mitigating risk.*

This chapter begins with a case study of the climate risk assessment (CRA) of the Strategic Development Action Plan for the Niger River Basin (NRB) and then describes the various issues to consider when planning adaptation to climate change.

### The Niger River Basin Case Study

The Niger basin (figure 7.1) is an important basin in West Africa with nine riparian nations (Benin, Burkina Faso, Cameroon, Chad, Côte d’Ivoire, Guinea, Mali, Niger and Nigeria). In 1964 an agreement was signed between the riparians to promote cooperation in the basin with the establishment of the Niger River Commission. The Niger River Commission was replaced by the Niger Basin Authority (NBA) in 1980 and the NBA was given a broader mandate by the Heads of State and a long-term objective to promote cooperation between

and among the Member States and to ensure integrated development in all areas as part of development of the basin’s resources. Faced with mounting development challenges that required joint action, the heads of state of the Niger Basin decided to develop a Shared Vision and an integrated Strategic Development Action Plan (SDAP) in 2002. An agreed Shared Development Vision was adopted by the Heads of State in 2006 and work continued on drafting the SDAP and Investment Program (IP). The SDAP was endorsed by the NBA Council of Ministers (CoM) in 2007 and the IP was endorsed by the Heads of State in 2008. Climate change was not considered in the analytical work on which the SDAP was based, but by 2008 climate change had become a major concern of several member countries; at the time of approving the IP, the heads of state requested that the climate risks that could affect the IP be identified and appropriate measures formulated to manage these risks. In September 2009, the CoM sought World Bank assistance in this regard.



Sources: Based on data from - Active basins and rivers (BRL, 2008), more detailed rivers, lakes, and reservoirs (RWDRB/CIA, 2006), inactive basins (Carmen Revenga and Petrol Doll, 2004).  
**Figure 7.1 The Niger Basin is a significant basin in West Africa**

### Current situation in the basin

In terms of Geography, the Niger River Basin is bounded approximately by latitudes 5° and 22° N and by longitudes 11°30' W and 15° E. It extends 3,000 km from east to west and about 2,000 km from south to north. The total basin area is 2,240,000 km<sup>2</sup> out of which 1, 500,000 km<sup>2</sup> is hydrologically active. Owing to its boomerang shape, the Niger Basin cuts across all of the major climatic and ecological zones of West Africa. These include the Guinea Savanna vegetation belt in the headwaters in the Fouta Djallon Massif in Guinea, through the semi-arid Sahel Savanna zone in the middle reaches, to the Tropical Mangrove forests at the mouth of the river in Nigeria's Niger Delta.

The population of the basin is estimated to be approximately 110 million. The population is projected to rise to about 155 million by 2025 and to 252 million in 2050. About two-thirds of the people live in rural areas where livelihoods depend on rainfed agriculture and livestock. Forty-five percent of the people in the basin depend on surface water for drinking, livestock, and other household needs. In recent years the basin countries have invested heavily in groundwater development for rural water supply. Poverty is widespread in the basin countries. Although there has been important irrigation development, particularly for rice production, about 70% of agriculture in the basin is rain fed. Access to electricity is low and water management infrastructure (including storage infrastructure) is limited.

### The SDAP and the Climate Risk Problem

The SDAP involves the investment of \$7.8 billion over the next 20 years from 2008 to 2027<sup>8</sup>. The SDAP includes:

- Socio-economic infrastructure (\$6.24 billion) including: common interest and transboundary infrastructure (\$5.1 billion); rehabilitation of two existing hydropower sites; construction of three large new dams and other storage (\$2.6 billion); construction of new hydro-agriculture infrastructure (265,000 ha, \$1.9 billion);
- Economic development other than by means of large-scale infrastructure (\$0.74 billion) including agriculture, fisheries, livestock, and tourism;
- Development of other essential infrastructure and basic services (\$0.41 billion) including transport, WSS, and health;
- Ecosystem conservation and resource protection (\$1.2 billion) including protection of biodiversity, erosion control and sand/silt control, and prevention of water pollution;
- Capacity building and stakeholder involvement in IWRM (\$0.35 billion)

While the SDAP is comprehensive and reflects an integrated approach to development, it is evident that the primary focus over the next 20 years will be on putting in place major water management infrastructure to enable development – mainly water storage. The large SDAP investment in water storage is expected to reduce poverty and food insecurity through expansion of irrigated agriculture, increase energy production and access to electricity, stabilize and maintain required stream flows at critical points and at critical times in the basin, support expanded fisheries production including aquaculture and support expansion of livestock and tourism.

<sup>8</sup> Financial pledges for implementation of the priority investments to be undertaken in the first five years presently total about \$1.5 billion.

The SDAP is fundamentally a program to improve water management in ways that support and enable economic and social development. Hence the development outcomes being sought are dependent on how well these infrastructures and the people who will operate them are able to manage hydrologic variability that is driven in part by climate variability.<sup>9</sup> Therefore, the vulnerability of the SDAP to climate variability and change needs to be measured in terms of changes in these outcomes that occur because of climate and hydrologic variability.

Table 7.1 is a consensus summary of the key indicators of adverse change in the SDAP outcomes by sector as reached in discussions among the countries.<sup>10</sup> The climate risk assessment problem is to determine the likelihood or probability that any of these indicators would change beyond a critical threshold of acceptability because of climate change.<sup>11</sup>

**Table 7.1 Initial SDAP Climate Vulnerability Indicators**

Domain or Sector	Vulnerability Indicator
<b>Agriculture – Irrigation</b>	<ul style="list-style-type: none"> <li>▪ Change or reduction in water availability</li> <li>▪ Reduction in area irrigated</li> <li>▪ Yield reduction</li> </ul>
<b>Energy</b>	<ul style="list-style-type: none"> <li>▪ Change in energy production (including dependable capacity)</li> <li>▪ Change in reliability of reservoir volumes and levels</li> </ul>
<b>Fishery (including aquaculture)</b>	<ul style="list-style-type: none"> <li>▪ Decrease in fish production</li> </ul>
<b>Livestock</b>	<ul style="list-style-type: none"> <li>▪ Decrease in meat and dairy production</li> </ul>
<b>Water Transport</b>	<ul style="list-style-type: none"> <li>▪ Reduction in number of days available at minimum river water depth for different classes of navigation</li> </ul>
<b>Health</b>	<ul style="list-style-type: none"> <li>▪ Adverse changes in the prevalence rate of water borne and climate sensitive diseases</li> <li>▪ Changes in conditions that support spread of climate sensitive diseases</li> </ul>
<b>Biodiversity and Ecosystems</b>	<ul style="list-style-type: none"> <li>▪ Reduction in the reliability of minimum guaranteed river flows at agreed points</li> <li>▪ Change in the number and diversity of aquatic and faunal species</li> </ul>

<sup>9</sup> The climate drivers of hydrology are precipitation and temperature. But the hydrology of the basin, as it is manifested in the amount of runoff, streamflow or groundwater recharge, is also dependent on the status and changes taking place in the physical characteristics of the basin including, for example, land cover, soils, etc.

<sup>10</sup> Final Report on the First Workshop on Climate Risk Assessment; Niger Basin Authority (NBA) and the World Bank; May 24-26, 2010; Ouagadougou.

<sup>11</sup> Hence for each of these indicators a metric and threshold needs to be defined as well.

### The challenges of a climate risk assessment

The “bottom up” approach to climate risk assessment described in Chapter 6 was used in the NRB climate risk assessment. The analytical framework is outlined below in Figure 7.2. In this process there are four key elements in the process of estimating SDAP climate risks”:

- First, one must have some means of estimating or deciding upon the change in precipitation and temperature (the main consequence of climate change) for which one wants to test the performance of the SDAP – In this case study, estimated values of P and T in 2030, 2050 and 2070 from 39 Global Climate Model (GCM) runs from 15 different models were used;
- Second, one must be able to estimate changes in runoff and hence streamflow based on the estimated changes in P and T – The linkage between estimates of climate change and system function or operation is a hydrologic model that translates changes in P and T into changes in runoff and streamflow;
- Third, the SDAP and existing infrastructure constitute a water management *system* and a water system simulation model is used to analyze the function and operation of the system under each of the hydrologic and runoff regimes that result from climate change; the results of each simulation are the values of the vulnerability indicators associated with that regime;
- Lastly, risk is the product of the vulnerability (e.g., change in energy production) to an event (e.g., change in runoff) times the probability that such an event might occur; hence the fourth element of the approach is to estimate the probability or likelihood that specific changes in P and T might occur.

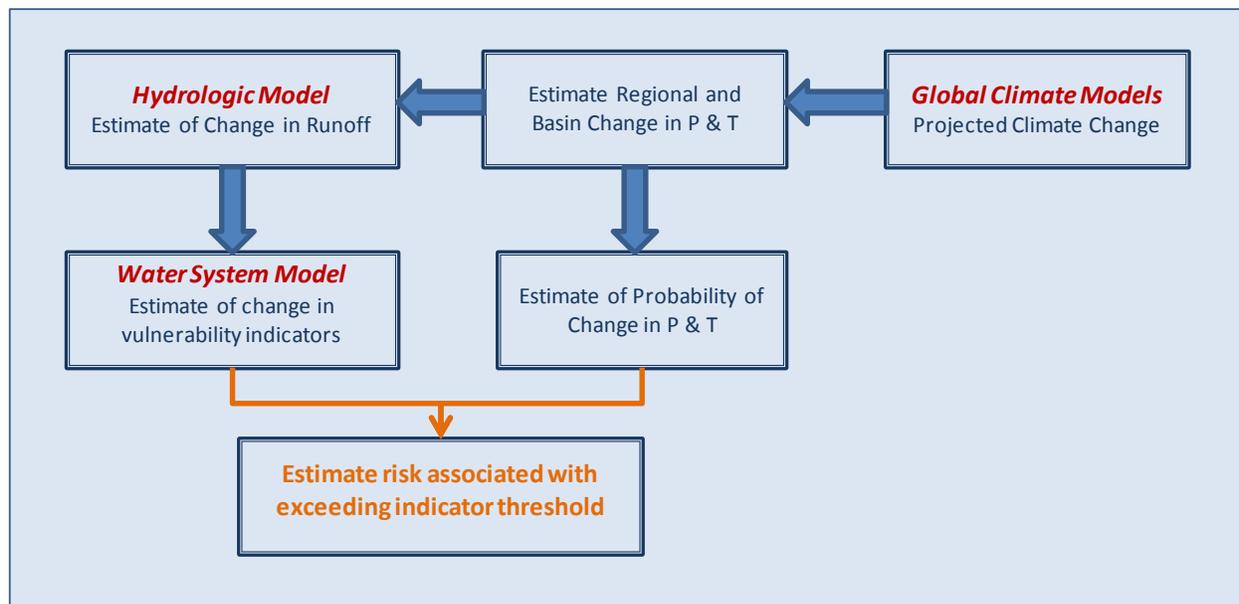
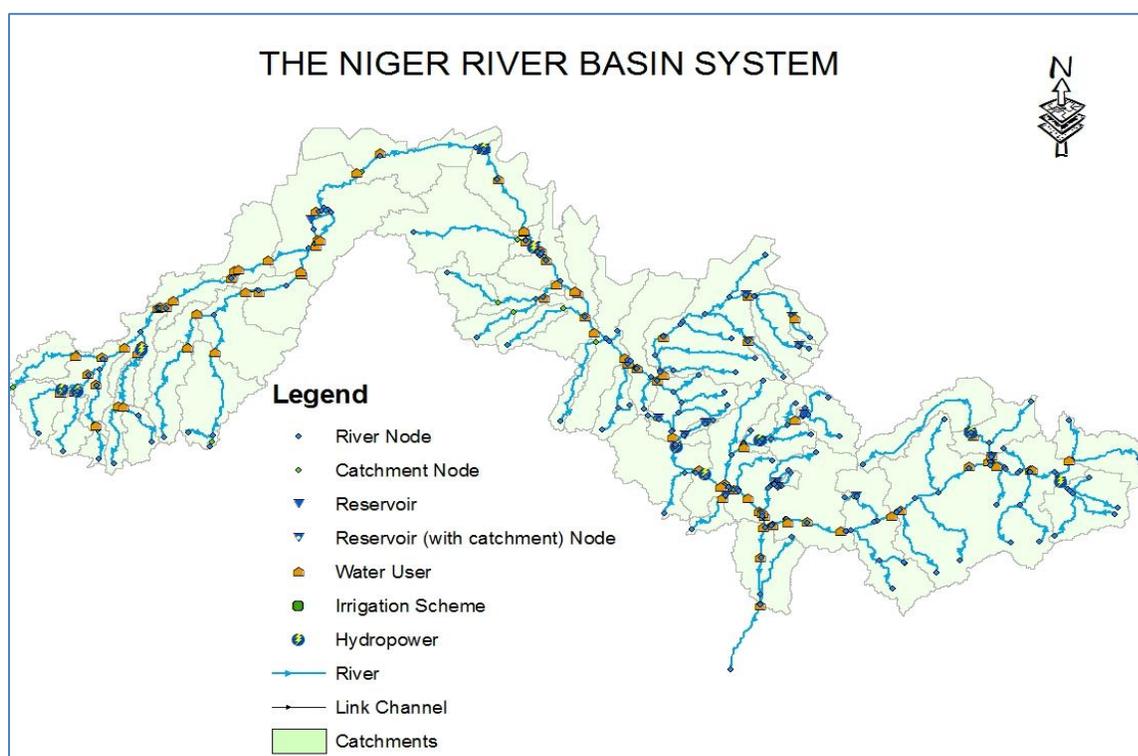


Figure 7.2 The overall analytical framework for estimating climate change risk (P is precipitation and T is temperature)

### Available tools and data for the SDAP climate risk assessment

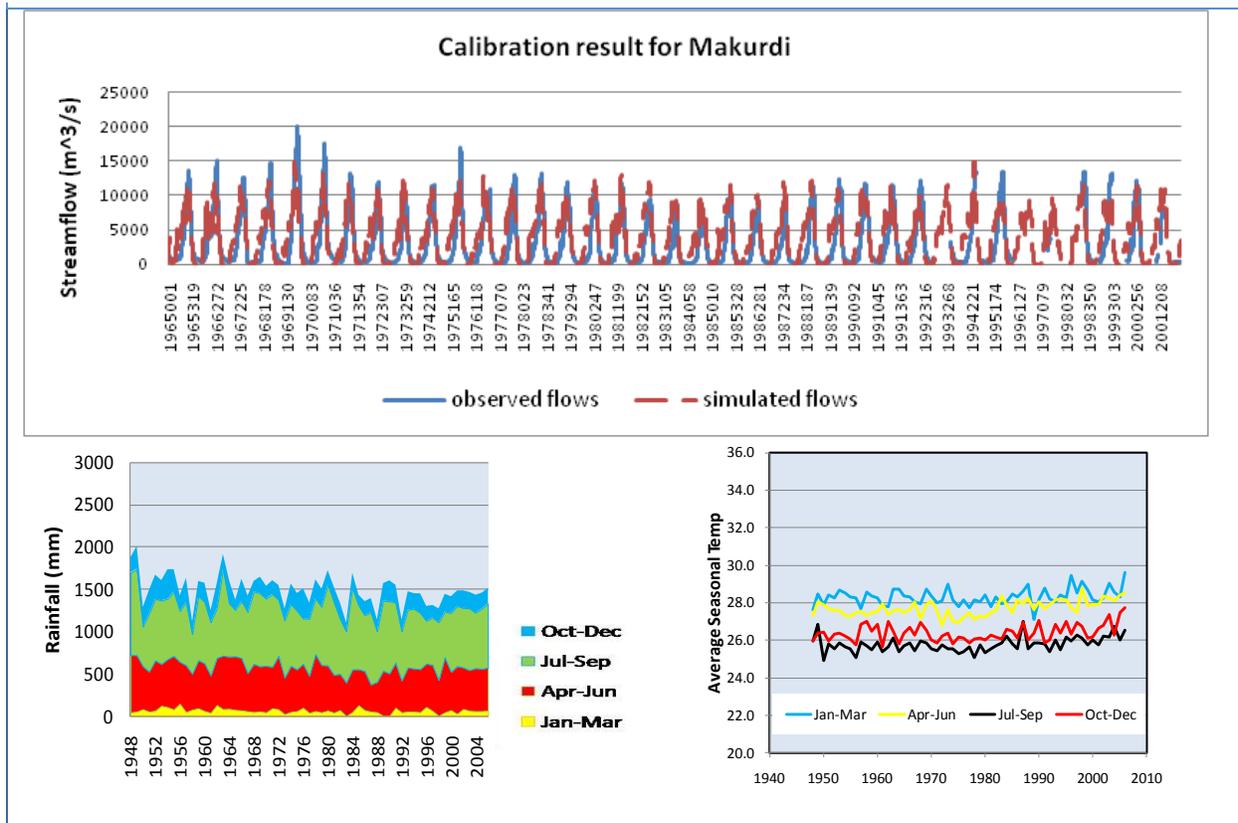
As a part of the preparation of the SDAP a simulation model was established and calibrated for the Niger River Basin that was made available to the case study team by NBA.<sup>12</sup> The schematic diagram of the basin used in constructing the model is shown in Figure 7.3. The model includes about 85 catchments or subbasins, all existing and proposed infrastructure (including 21 existing dams, 4 planned dams, and 10 hydropower generating stations), and a number of development zones in which agriculture and other water demands and water uses (at 134 nodes) are modeled.

A hydrologic model of the basin has been developed by the NBA's partner organization, AGRHYMET (*Centre Regional de Formation et d'Application en Agrométéorologie et Hydrologie Opérationnelle* – Regional Center for Training and Application of Agrometeorology and Operational Hydrology) that is being used to improve flood forecasting in the upper basin; In the case study the model was expanded to cover all sub-basins and catchments, and the data base was updated and supplemented to improve calibration. However complete calibration has been difficult because of the large inner delta that separates the upper from the middle and lower basins. Calibration is excellent above and below the inner delta (Figure 7.4) but further study and analysis will be required upstream and downstream of the delta.



**Figure 7.3** The Niger River Basin schematic diagram used in the simulation of the water system

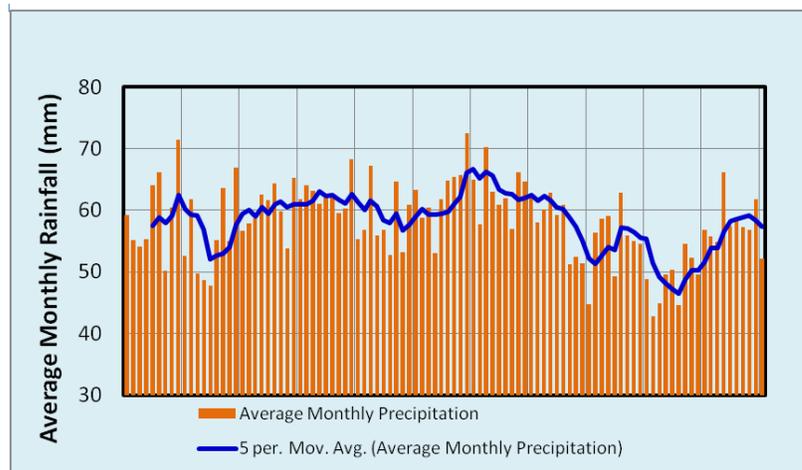
<sup>12</sup> BRL Ingenierie, Danish Hydraulic Institute (DHI), *Establishment of a water management model for the Niger River Basin*, Niger River Basin Authority, July 2007



**Figure 7.4 Hydrologic model calibration results at Makurdi (on the Benue River – a major tributary of the Niger River) and historical seasonal rainfall and temperature at the same location.**

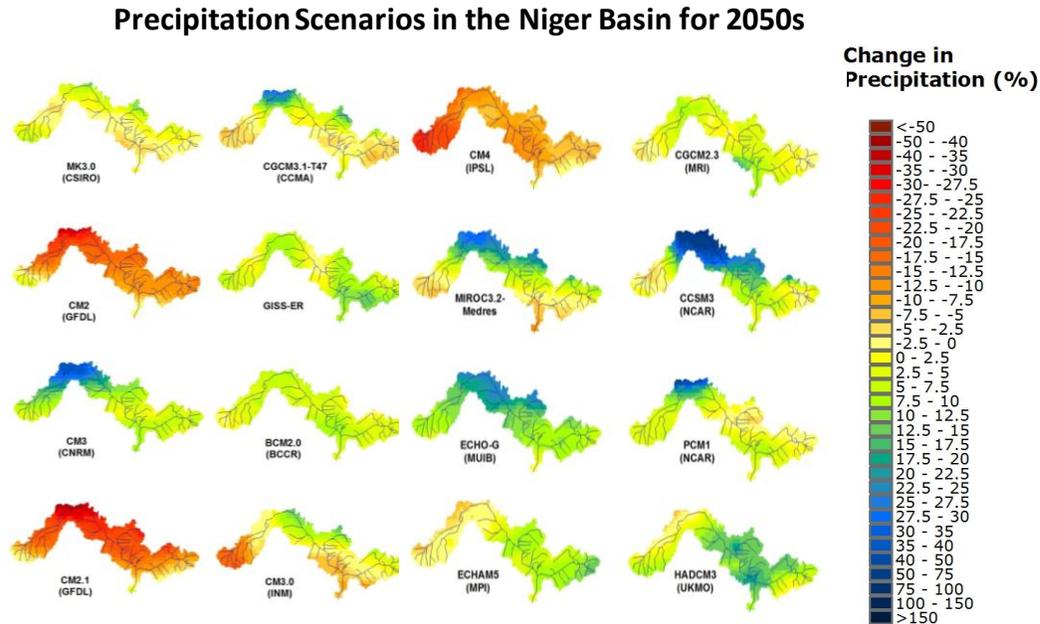
**The general picture of climate and climate change in the Niger River Basin**

In order to effectively address the impacts of future climate change, it is essential to first understand—and cope with—observed variability, since climate change may build upon and exacerbate historical patterns. The Niger Basin is prone to large climatic variability at different scales—including inter-annual, multiyear, and decadal (Figure 7.5)—as well as spatial variability. This variability represents the greatest climate risk to the SDAP and its IP.



**Figure 7.5 Historical precipitation variability in the Niger River Basin**

The spatial variation in projections of future temperature and precipitation in the Niger Basin made by different Global Climate Models (GCMs) under the SRES<sup>13</sup> A2 scenario are shown in Figure 7.6. There is a wide disparity in precipitation scenarios across models (even within the same Special Report on Emission Scenarios [SRES] and for the same time frame); it is unlikely that any sensible conclusions can be drawn from a detailed analysis of such scenarios using the hydrologic and system models. Similarly, changes in variability/extremes are not well indicated by current GCMs



This map shows the precipitation change projected by the considered climate model, under the A2 scenario for 2040 - 2069 as compared to 1961 - 1990. Map displays gridded data (cell size=0.5dd).

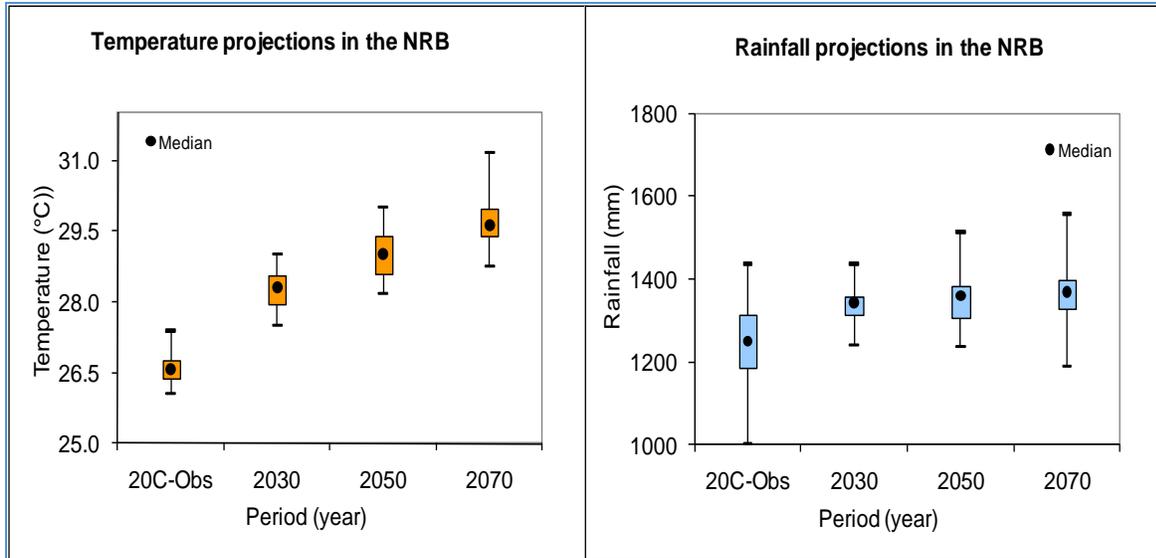
Sources: Based on data from the Climate Wizard (<http://www.climatewizard.org>) developed by The Nature Conservancy, The University of Washington, and the University of Southern Mississippi)

### Figure 7.6 Which future scenario of precipitation should be used?

Figure 7.7 shows the projection of median temperature and precipitation for the Niger River Basin in 2030, 2050 and 2070 as well as the observed historical period (1980-1999) in the 20<sup>th</sup> century (20C-Obs) based on an ensemble of results from 15 GCMs totaling 39 runs. The box around the median value indicates values +/- one standard deviation from the median, and the lines drawn from the boxes indicate the extreme values in the ensemble of results for the indicated period.

Figure 7.7 suggests a dramatic rise of 2-3 °C in temperature by 2070, and the spread or degree of variation among the estimates is not large until 2070 when uncertainty is greatest. The projections of change in precipitation are very modest even in 2070 but the spread among the estimates is large and increases consistently over the period. Note the large variation in estimates for precipitation among the GCMs for the observed period.

<sup>13</sup> Special Report on Emissions Scenarios (SRES), Intergovernmental Panel on Climate Change (IPCC)



**Figure 7.7** Climate change projections for T & P based on a “super ensemble” of 15 GCMs and a total of 39 runs.

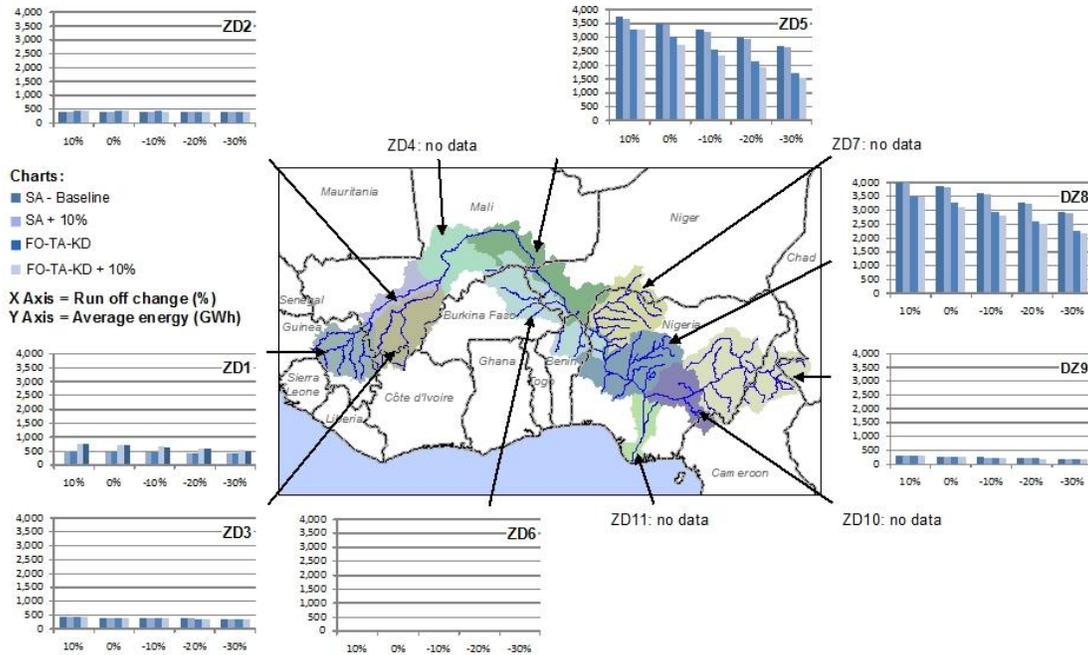
In Figure 4.8 the historical observed annual change in precipitation (as a % of the annual average) is compared with the GCM projections of change in annual precipitation by overlaying the historical record onto the projected future. The aim is to show that the degree of variability and extreme change in the historical observed precipitation record in the Niger River Basin is perhaps more adverse than that suggested by the climate change projections. This suggests that at least through 2030 to 2050, the NBA and the basin countries should ensure that the SDAP and the IP are able to manage the variability and extremes observed in the historical observed precipitation record. The projections based on current GCMs are not really a concern.

But as noted above and in Figure 7.7 the projections of temperature change in the Niger River Basin are another matter. Temperature influences runoff through changes in evaporation and transpiration and it influences water demand by plants, crops, and livestock, and reduces reservoir storage. The changes indicated in Figure 7.7 could affect irrigation water demands by as much as 5% increasing water use by as much as 1.5 BCM per year and increasing reservoir evaporation by as much as 0.5 BCM per year.

### Estimating SDAP– IP risks

Without hydrologic models and climate change data one can learn a lot about how and to what degree a water system is vulnerable to impacts from climate variability and change. Having identified the vulnerability indicators (Table 7.1) the water system simulation model can be used to estimate the impact of hypothetical changes in runoff, temperature and precipitation that are selected to represent both a range of extremes that might occur and a range of values that stresses the system and leads to unacceptable changes. In the first round of discussions with the Niger Basin countries this approach was used to get a picture of what the possible impacts on the indicators might be and to identify the *thresholds* – the level of change in each indicator beyond which change is not acceptable. One such result is shown in Figure 7.8 for hydropower production

**Sensitivity of Energy Production to Infrastructure, Water Demand, and Run-Off Scenarios, by Development Zones (ZD) / Sensibilité énergétique en fonction des infrastructures, de la demande en eau et du ruissellement, par zones de développement (ZD).**



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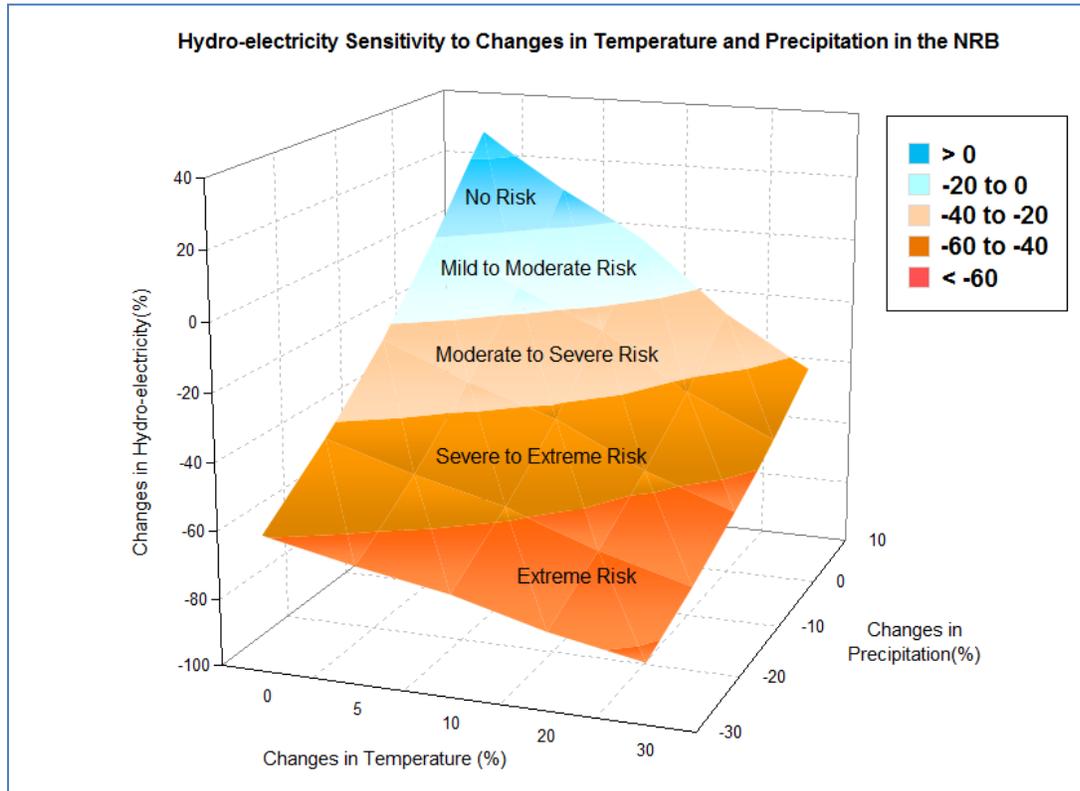
**Figure 7.8 Hydropower varies more because of irrigation development than climate**

Physically-based models often lead to more reliable estimates of the various components of spatially and temporally varying catchment hydrological process than empirical models. Nevertheless, since the hydrologic model of the Niger River Basin is not yet completely calibrated, an alternative approach was used to estimate runoff from estimates of future precipitation and temperature. Since the hydrological characteristics remain homogenous in the NRB, an empirical model of mean annual runoff as a function of precipitation using a log-linear regression model which simulated the relationship well ( $R=0.76$ ).<sup>14</sup>

The focus in the case study is to assess the severity of climate imposed risks and quantify their probability using future climate projections. Nevertheless, even if it is not possible to estimate these probabilities one can estimate risks by linking the hydrologic model to the water simulation model and reaching a consensus on what constitutes unacceptable levels of change. To do this one determines how equivalent changes in precipitation and temperature affect the catchment runoff in the NRB. Using the log-linear model, catchment annual runoffs were then generated for precipitation changes ranging from +10% to -30% and temperature increase ranging from 5% to 30%. The water system simulation model is used to estimate the Impacts of changes in streamflow on the vulnerability indicators – the water system simulation model links streamflow changes to the climate conditions that would cause them.

<sup>14</sup> World Bank, *Interim Technical Report on the Climate Risk Assessment*, August 2010. (Insert URL here)

Based on the consultation with basin stakeholders in a May 2010 workshop in Ouagadougou<sup>15</sup>, reductions of 20% from the baseline performance were considered significant impacts. With this guidance, five risk levels were identified ranging from “No risk” to “extreme risk”. These levels are defined based on arbitrary choice of percentage shift in runoff relative to baseline operations. Figure 7.9 is an example



**Figure 7.9 Climate risks to hydro-electricity production in the NRB**

Probability distribution functions (PDFs) and cumulative distribution functions (CDFs) are constructed based on climate projections from 39 ensembles and the relationship obtained previously between catchment runoff and individual metrics at basin scale. For comparison, the exceedance probabilities of the identified risks for various metrics are tabulated in Table 7.2. Generally, the assessment indicates that the shape of the distribution curves for hydro-electricity, navigation and environmental flows resemble similar, which suggests that the probabilities of risk levels are similar for these metrics.

<sup>15</sup> Final Report on the First Workshop on Climate Risk Assessment; Niger Basin Authority (NBA) and the World Bank; May 24-26, 2010; Ouagadougou.

**Table 7.2 Exceedance probability of climate risks for various metrics in the NRB**

Exceedance Probability (%)	Period (Year)	Hydro-elect. (GWh)	Navigation (days)	Wet season Irrigation (ha)	Dry season Irrigation (ha)	Flooding in Delta (km <sup>2</sup> )	Environmental flows (m <sup>3</sup> /s) at			
							Markala	Border M-N	Niamey	Malanville
P(x > Mild risk)	2030	49%	51%	0%	0%	48%	48%	50%	50%	50%
	2050	65%	64%	0%	0%	68%	68%	64%	66%	66%
	2070	75%	76%	0%	0%	76%	76%	74%	76%	76%
P(x > Moderate risk)	2030	0%	0%	0%	0%	0%	6%	10%	8%	8%
	2050	10%	8%	0%	0%	6%	22%	28%	24%	26%
	2070	20%	18%	0%	0%	14%	32%	40%	34%	36%
P(x > Severe risk)	2030	0%	0%	0%	0%	0%	0%	0%	0%	0%
	2050	0%	0%	0%	0%	0%	0%	8%	4%	6%
	2070	0%	0%	0%	0%	0%	8%	14%	12%	12%
P(x > Extreme risk)	2030	0%	0%	0%	0%	0%	0%	0%	0%	0%
	2050	0%	0%	0%	0%	0%	0%	0%	0%	0%
	2070	0%	0%	0%	0%	0%	0%	0%	0%	0%

\* x = metrics

By comparison, climate change impacts lies between “No” to “Mild” risk for 2030, and between “mild” to “moderate” risk for 2050 and 2070 for most metrics in the NRB. There is a slight chance of severe risk for environmental flows requirement at Markala (8%), Niger-Mali border (14%), Niamey (12%) and Malanville (12%) in distant future (2070).

### Planning ahead

These early results represent a work in progress. Much more work with the NBA stakeholders is required to better establish thresholds for these system performance indicators and to better define the ranges of acceptability (and non-acceptability). Additional analyses are required to move from the sensitivity analysis on runoff (considered to include running an ensemble of available GCM outputs for the basin through the hydrologic model and then the systems model) to examining implications for the performance indicators. But the results so far do give a clear indication of the relative importance of considering climate and development scenarios and also of considering historical climate variability when conducting a CRA.

The results also give some idea of possible adaptation measures that might improve system performance indicators. These include:

- **Information.** Improvement in weather forecasts and real-time decision support systems for operational and flood management would enable reservoir operations to optimize hydropower, balance irrigation demands with other uses, and better manage floods and droughts.
- **Institutions.** There is a strong need for capacity building at all levels, from the NBA to individual farmers, to better cope with climate risks—primarily risks that the basin has already experienced—as well as the more important development implications of new investments and their coordinated operations.
- **Investments.** The SDAP appears to be able to do what it promises in terms of improving many of the system performance indicators. Further work will be required to examine additional investment options (for example, water conservation and efficiency improvement measures) that could further address evolving climate and development risks and improve system performance.

***This example illustrates how a CRA framework—as described in chapter 6—can be applied to water-related investment plans.*** But it is essential that the framework be thoughtfully applied to each system chosen—be it a single project, a cascade, a sectoral plan, or an overall basin plan. It will be necessary to customize the approach to the system chosen, the performance indicators, the availability of data and

existing calibrated modeling tools, and the institutional setting. But the framework does provide guidance on the kinds of issues to keep in mind while evolving climate-smart development strategies.

The following sections outline steps toward climate-smart development strategies that internalize adaptation and possibly also mitigation options. It will be useful to keep in mind the alternative typologies of **adaptation options** that can be considered in order to reduce climate risks.

**There are many challenges in water planning, especially under uncertain climate conditions.** It is probably inevitable that just as today’s water managers—from farmers and water-use associations to urban water and hydropower utilities and resource managers and operators—attempt to make the best estimates under uncertain conditions, tomorrow’s water managers will continue to do the same, albeit with additional uncertainty to account for in their assessments. Complicating the choice of adaptation options is managers’ coping capacity. Since vulnerability is a function of this capacity, one must consider a mix of social, economic, institutional-strengthening, capacity-building, and technical approaches to managing the potential risks outlined in chapter 6. In operationalizing the framework proposed, there are a number of challenges. These include challenges relevant to the three I’s:

- **Information.** Many basins in Africa lack a reliable and updated climate-, water-, and development-related knowledge base. Few have modern system models that are acceptable to all riparians. Hydroclimatological networks are poor—affecting not just forecasting but also the very basis of the GCMs and their operation.
- **Institutions and instruments.** Most basin agencies and national water agencies in Africa face significant obstacles to gathering the skilled human resources needed to undertake the modern information systems, modeling, and structured stakeholder consultation efforts that are essential for effective CRAs and the implementation of climate-smart strategies. Modern water management instruments such as zoning, insurance, and water rights are not well established in Africa.
- **Investments.** The current level of investment is low, reducing the capacity to undertake “adaptive adaptation” measures (for example, changing operating rules to provide more flood cushion) or providing redundancy buffers (for example, in case of water supply or hydropower shortfall).

In fact, the challenges listed above indicate future priorities, with specificities to be determined by the application of the framework to particular systems. The three I’s (information, institutions, and investments) form the typology of climate adaptation options. In designing climate-smart measures, there is a need to take into account historical climate *variability* in investment design (no-regret investments improve climate resilience). It is also critical to take climate *change* into account where investments could experience significant high-regret climate change implications during their economic life (strategic climate insurance investments). In some cases, short-term pilot programs could serve to lay the groundwork and learn lessons for scaling up new climate change adaptation paradigms in the long term (for example, through crop research). Decisions regarding investment design will need to be made in the context of high uncertainty and often high regret. All these investment choices require a focus on planning and implementation, which in turn places a premium on information and institutions.

**There are many ways to cut the adaptation deck.** For example, one can prioritize basic climate-smart development options by dividing them into the following four categories (Willows and Connell, 2003) in descending order of priority:

- **Win-win options.** Options and combinations of options that mitigate the risk (in part or in whole) and are cost-effective. These options include many integral to a comprehensive approach to agricultural development in a particular context—options that would be included without considering climate change or historical variability, and additional options that enhance the resilience of the socioeconomic system.
- **No-regret options.** Options that are cost-effective, enhance productivity and resilience, and leave no regret if the actual path of climate change creates little or no additional risk above what would be expected from historical variability. These additional options are suggested by the apparent plausibility or likelihood of additional climate risk from today’s perspective.
- **Low-regret (or limited regret) options.** Options with modest cost but whose benefits, which may be very large, are actually realized only if the projected changes occur. Because of the low cost and the uncertainty involved, these options take an insurance-like approach when the likelihood of the vulnerability seems large (in terms of overall harm to project outcomes).
- **Flexible (scalable, adjustable) adaptation options.** Options that can be designed to be scalable or adjusted in the future as the actual path of climate change emerges. Reservoirs, diversion headworks, and boreholes are examples of irrigation system components that can be scaled if this approach is adopted at the beginning. Agricultural research is another example of an option that can be scaled up or intensified, or its direction changed, as future conditions emerge and improved monitoring systems better detect them.

Stakhiv (2010) has outlined five ways in which water managers can adapt to existing climate variability while waiting for a new generation of tools to improve our understanding of climate change:

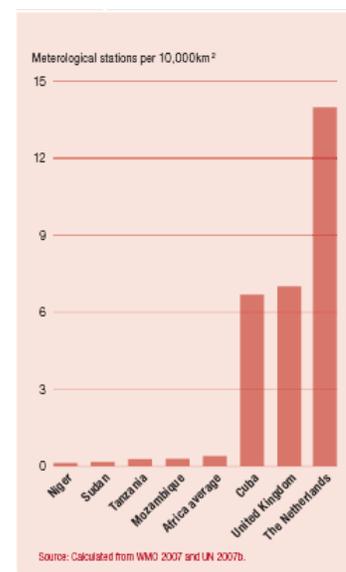
- Plan **new investments** for capacity expansion (reservoirs, irrigation systems, levees, water supply, wastewater treatment).
- **Operate, monitor, and regulate existing systems** to accommodate new uses or conditions (for example, ecological conditions, climate change, population growth).
- Maintain and undertake **major rehabilitation** of existing systems (for example, dams, barrages, irrigation systems, canals, pumps, and so on).
- Modify **processes and demands** (water conservation, pricing, regulation, legislation) for existing systems and water users.
- Introduce new **efficient technologies** (desalting, biotechnology, drip irrigation, wastewater reuse, recycling, solar energy).

Stakhiv also indicates that the established water resource management concept of *adaptive management*—defined by the National Research Council (2004) as a process that “promotes flexible decision-making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood”—is still valid in a world undergoing climate change.

This report attempts to organize a range of climate-smart measures that are valid both today and in a climate-changed world into the framework of the three “I”s, as summarized below:

### Information

- **Invest in improving hydro-meteorological networks to improve information access** (see figure 7.10 for the poor state of such networks in Africa). The United Nations Framework Convention on Climate Change (UNFCCC) has recognized the lack of observational climate data in Africa as a key constraint to understanding current and future climate variability. Significant gaps in climate data exist in (i) observations for local use, (ii) data coordination with user communities, (iii) observations for national and regional planning early warning, and (iv) observations for global change (IRI 2006).
- **Collate knowledge base** on climate variability, change (recognizing uncertainty), impacts, vulnerability, and adaptation options related to water resources. This kind of systematic knowledge collation, which is currently absent, is critical for planning and implementing any climate change strategy.
- **Improve intermediation between the scientific and development community on climate change and water resources.** There is a necessity to improve knowledge partnerships and collaboration between the scientific and development communities. This is essential to ensure both that the latest scientific advances are reflected in development assistance as well as that the scientific questions explored are shaped by development decision needs.
- **Improve awareness of water-related climate risks and their management.** Although there is increasing awareness of climate risks, it is important that stakeholders at all levels become more aware of the specifics of climate-smart development planning.



**Figure 7.10 The climate information deficit in Africa**

### Institutions and Instruments

- **Promote appropriate water institutions** (for example, transboundary and in-country river basin organizations). There is a need to promote appropriate institutional mechanisms that help countries manage climate risks—and this inevitably requires regional cooperation given that Africa’s water (which is the primary resource impacted by climate change) is fragmented into over 160 international river basins. Countries and their development partners must be prepared to undertake the long journey toward cooperation from suboptimal and often unsustainable unilateral approaches.
- **Build the capacity of regional and national entities** (for example, river basin organizations, regional and national centers for climate change) in effective climate risk planning and management. Through knowledge partnerships, access to local and international expertise, and financing for capacity-building activities, basin and climate/disaster management institutions must be modernized. The World Bank Strategic Framework for Development and Climate Change (World Bank 2008) also highlights the need to improve research, knowledge, and capacity-building for effective climate risk management.
- **Improve criteria for design and operations** (for example, design floods, reservoir life, operational service indicators and thresholds, and so on). There is an often unrecognized need to identify critical criteria for the design and operation of water infrastructure to enable setting and

monitoring of implementation and operational targets of performance under climate change. In the absence of such an approach, adaptation responses will be “shooting in the dark,” and it will never be clear if the adaptation measures have worked or if they are sufficient or excessive.

- **Build strategic partnerships.** There is a need to build strategic partnerships in Africa—both at the knowledge and development finance levels—in order to synergistically work toward improving adaptation to climate risks and to avoid fragmented attempts. This includes partnerships in information/analysis, training, identification of adaptation options, consultation, financing, and implementation/monitoring.
- **Target financing for climate change adaptation.** There are a number of funds targeted at climate change that are under consideration. It would be unwise to prevent the use of any “adaptation funds” for adapting to existing (and evolving) climate risks and insist on climate change incrementality. To consider holistic development and avoid irrationally skewed incentives, the focus could shift from climate *change* adaptation to climate *risk* adaptation, or climate-resilient development.
- **Establish policies to diversify economies away from sectors exposed to water-related climate risks.** Where there are no easy ways to adapt to climate risks, the country may be better served by moving the economy to sectors that are less impacted by hydrologic variability or climate risk (and human, infrastructure, and natural endowments and visionary leadership are needed to diversify into areas such as information technology, entertainment and other services, mining, tourism, and so on).
- **Create international water agreements across African trans-boundary basins.** Given the large number of trans-boundary basins in Africa, and the precious few that have or are inching toward riparian agreements, a critical adaptation focus needs to be to stimulate cooperation (backed by agreements) across the riparian states to promote the basin approach that is so essential to effectively managing climate risks.
- **Establish insurance schemes.** Some countries have schemes to protect farmers and others when they are devastated by floods, droughts, or storms. These are sometimes in the form of a “bail-out,” which may not induce different behavior that better recognizes climate risks in the future. A good insurance scheme may provide the incentive (for example, through premium signals) to take actions to reduce climate risks, while providing an important social safety net that is often absent.
- **Improve water entitlement management.** An evolving instrument for climate risk management may be to use an instrument that is gaining importance for integrated water resources management—better defining water rights or entitlements and allowing their transfer under transparent circumstances. This can help move water to its higher-value uses gradually, over time, factoring in climate change.

### Investments

- **Review and restructure current and ongoing investments to better manage climate risks.** There is a critical need for countries and development institutions to review their current portfolio and pipeline both to identify climate risks that can be addressed but also to identify avenues to initiate adaptation to or the mitigation of climate risks.
- **Promote critical investments in water storage** (from rainwater harvesting to large storage) conceived in a basin context and encompassing environmental, social, and economic aspects. A basin context is essential to conceive any large storage investments, both to recognize the transboundary nature of impacts, but also to carefully evaluate if the tradeoffs with system losses (for example, undue evaporation from building a dam in an increasingly hotter area) are appropriate.

- **Improve flexibility in water management.** Perhaps the most important investment that can be made given the uncertainty in model predictions of localized impacts in space and time is to build *flexibility* for climate risks. This can be achieved in many ways—such as by improving system efficiency and conserving water (for example, by using drip sprinklers), building small check dams (rainwater harvesting structures) in watersheds to buffer climate shocks, and developing alternative water supplies for service capacity expansion in critical areas (for example, large cities).

**But all these options are robust only to some level of uncertainty.** A problem that emerges is that some options have thresholds beyond which they no longer function effectively. For example, dikes or bunds have limits with respect to the flood stage they can protect against; distribution canals and pipes are not easily or inexpensively enlarged; boreholes, once the screen is set, have limits on the depth of the aquifer water level that can be utilized; and reservoirs—for a variety of physical and economic reasons—may have limits on the total potential storage that can be used (note that these may be further diminished if sediment loads are underestimated or watershed measures meant to reduce erosion fail). Similarly some options may have limited functionality under high degrees of uncertainty and variability. Large-scale structures are an example because of the need for definite and accurate design criteria (sediment loads, hydrologic extremes, and so on). Such options may not be robust enough to perform cost-effectively over a wide range of future conditions, leading to reexamination of the “acceptable” thresholds of system performance indicators by examining the cost-benefit tradeoffs.

**Probably the best first step to adapting to future climate change is to adapt to the existing climate risks to which most countries in Africa are still highly vulnerable.** For example, improving resilience to current exposure to floods, droughts, and storms, and the high variability of rainfall and stream flow, will involve improving flexibility in water management and demand management, improving investments in critical infrastructure such as storage (including traditional water harvesting structures), improving information management and forecasting, and increasing the institutional capacity for water resources planning and operation of water infrastructure. But in most cases (for example, drought and flood preparedness, watershed development, and so on), it is difficult to identify what “different things” should be done, and so activities may just involve doing the *same* things differently, with emphasis on vulnerable regions, farmers’ coping capacity and skill, reprioritization of activities, or scaling up financing from small-scale demonstration activities and pilots to a scale that makes a difference. Brown, et al. (2010a) indicate that African nations may want to focus on some promising, currently underutilized opportunities in improved climate information systems, diversification of crops and livelihoods, better water management including on-farm and community level storage, financial risk transfers such as index insurance, improved market access through market development, transportation and storage, and finally, protection from hydrometeorological hazards.

**An overall adaptation strategy is simply to spur economic development in Africa,** given that countries and communities with more resources are in a better position to absorb shocks and adapt to a changing climate. It should be noted that many of the current water-related investments in Africa are already supporting adaptation to existing climate risks (for example, investments in capacity building for water resources planning and management, water infrastructure, and transboundary cooperation). To improve adaptation to climate change, it is essential that these activities are scaled up and better targeted to areas and sectors vulnerable to climate change. Long-term plans in highly climate-vulnerable areas could include diversifying livelihoods and the economy away from activities that involve excessive climate risks (for example, by providing more irrigation where water is not a constraint, building power interconnections to better take advantage of hydrologic complementarities and manage risks, shifting to

less water-intensive crops, or focusing on sectors such as information technology and other services where countries have comparative advantage in fields that are not as climate dependent).

***There is a need to consider adaptive adaptation to gradually build capacity to more effectively manage climate change risks.*** Capacity building, institutional strengthening, and reform are long-term processes whose major impacts on sector performance, poverty, and growth can often require decades to fully achieve the intended outcomes in terms of scope and breadth of impact. Current climate variability as it impacts agricultural systems and farmers is an immediate problem to be addressed, but the longer-term effects of climate change will emerge gradually, affording an opportunity to concentrate on awareness, capacity building, testing, and adaptation options (agricultural research, advisory services, monitoring, and planning). The critical issue in this regard, for the present, is to identify and fill knowledge and capacity gaps in time to avoid adverse impacts. Also, while many would argue that the underlying processes that are driving climate change are already under way and are manifested in significant or at least noticeable change, the level of uncertainty in future scenarios (especially of precipitation and runoff) may be reduced as models improve. Since the trends will overlay the existing and perhaps changing pattern of significant intra- and inter-annual variability, the true picture and its potential consequences will not be easy to detect. Therefore, both monitoring and periodic assessments need to be institutionalized and substantial technical capacity developed and supported.

***In conclusion, water resources management has always had to deal with an uncertain climate, and the specter of climate change has made this a more complex task.*** But climate models have not advanced enough to provide area-specific operational guidance of investments catering to “development deficits.” As described in chapters 5 and 6 on the formulation and application of a CRA approach, much more can be done to adapt to existing “climate resilience deficits” and the more obvious climate change implications. It is also clear that the other (non-climate) parameters that are changing will shape the development paradigms of the future. These development paradigms can be made more “climate smart” by considering climate risk adaptation and mitigation measures.

Mainstreaming these measures into development decisions (for example, though a structured CRA process, as outlined in this document) appears to be a more rational use of climate-related financial resources. Any list of climate change adaptation measures is often identical to that required for effective development. Thus, it is often the case that good sustainable development *is* good adaptation! As indicated in this report, a silver lining of the current concern for climate change in water is that it has helped countries and their development partners to refocus on improved resource and investment *planning* for water resources development and management.

## Glossary of terms

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(Source: Bates et al, 2008, except where noted)

### **Adaptation**

A system response to a perturbation or stress that is sufficiently fundamental to alter the system itself, sometimes shifting the system to a new state (based on Turner et al. 2003).

### **Adaptive capacity**

The whole of capabilities, resources and institutions of a country or region to implement effective adaptation measures.

### **Adjustment**

A systemic response to perturbation or stress that does not fundamentally alter the system itself. Adjustments are commonly (but not necessarily) short term and involve relatively minor system modifications (based on Turner et al. 2003).

### **Blue water**

Blue Water is made up from run-off to rivers and deep percolation to aquifers that finds its way to rivers indirectly (Source: World Soil Information, <http://www.isric.org/content/green-water-concept>)

### **Climate**

Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

### **Climate change**

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

### **Climate model**

A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical or biological processes are explicitly represented, or the level at which empirical parameterisations are involved. Coupled Atmosphere-Ocean General Circulation Models (AOGCMs) provide a representation of the climate system that is near the most comprehensive end of the spectrum currently available. There is an evolution towards more complex models with interactive chemistry and biology. Climate models are applied as a research tool to study and simulate the climate, and for operational purposes, including monthly, seasonal and inter-annual climate predictions.

**Climate projection**

A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realised and are therefore subject to substantial uncertainty.

**Climate scenario**

A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate. A climate change scenario is the difference between a climate scenario and the current climate.

**Climate system**

The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface and the biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations and anthropogenic forcings such as the changing composition of the atmosphere and land-use change.

**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 spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

**Detection and attribution**

Climate varies continually on all time scales. **Detection** of climate change is the process of demonstrating that climate has changed in some defined statistical sense, without providing a reason for that change. **Attribution** of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence.

**Downscaling**

Downscaling is a method that derives local-to regional-scale (10 to 100km) information from larger-scale models or data analyses. Two main methods are distinguished: dynamical downscaling and empirical/statistical downscaling. The dynamical method uses the output of regional climate models, global models with variable spatial resolution or high-resolution global models. The empirical/statistical methods develop statistical relationships that link the large-scale atmospheric variables with local/regional climate variables. In all cases, the quality of the downscaled product depends on the quality of the driving model.

**Emissions scenario**

A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships. Concentration scenarios, derived from emission scenarios, are used as input to a climate model to compute climate projections. In IPCC (1992) a set of emission scenarios was presented which were used as a basis for the climate projections in IPCC (1996). These emission scenarios are referred to as the IS92 scenarios. In the IPCC Special Report on Emission Scenarios (Nakićenović and Swart, 2000) new emission scenarios, the so-called SRES scenarios, were published.

**Ensemble**

A group of parallel and model simulations used for climate projections. Variation of the results across the ensemble members gives an estimate of uncertainty. Ensembles made with the same model but different initial conditions only characterise the uncertainty associated with internal climate variability, whereas multi-model ensembles including simulations by several models also include the impact of model differences. Perturbed-parameter ensembles, in which model parameters are varied in a systematic manner, aim to produce a more objective estimate of modelling uncertainty that is possible with traditional multi-model ensembles.

**Exposure**

The contact between a system and a perturbation or stress (based on Turner et al. 2003).

**Flexibility**

The flexibility of a system refers to its ability to adapt to a wide range of operating conditions through relatively modest and inexpensive levels of redesign, refitting or reoperation (Hashimoto, T. et al., 1982a).

**General Circulation Model**

See *Climate model*.

**Greenhouse effect**

Greenhouse gases effectively absorb thermal infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus greenhouse gases trap heat within the surface troposphere system. This is called the greenhouse effect. Thermal infrared radiation in the troposphere is strongly coupled to the temperature of the atmosphere at the altitude at which it is emitted. In the troposphere, the temperature generally decreases with height. Effectively, infrared radiation emitted to space originates from an altitude with a temperature of, on average,  $-19^{\circ}\text{C}$ , in balance with the net incoming solar radiation, whereas the Earth's surface is kept at a much higher temperature of, on average,  $+14^{\circ}\text{C}$ . An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere, and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called enhanced greenhouse effect.

**Greenhouse gas (GHG)**

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour ( $\text{H}_2\text{O}$ ), carbon dioxide ( $\text{CO}_2$ ), nitrous oxide ( $\text{N}_2\text{O}$ ), methane ( $\text{CH}_4$ ) and ozone ( $\text{O}_3$ ) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, dealt with under the Montreal Protocol. Beside  $\text{CO}_2$ ,  $\text{N}_2\text{O}$  and  $\text{CH}_4$ , the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride ( $\text{SF}_6$ ), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

**Green water**

Green water is the water infiltrating into the soil, taken up by roots, used in photosynthesis and transpired by the crop (Source: World Soil Information, <http://www.isric.org/content/green-water-concept>)

**Hazard**

The threat of a stress or perturbation to a system's values (e.g. lives, livelihoods) (based on Turner et al. 2003)

**Hydrological cycle**

The cycle in which water evaporates from the oceans and the land surface, is carried over the Earth in atmospheric circulation as water vapour, condensates to form clouds, precipitates again as rain or snow, is intercepted by trees and vegetation, provides runoff on the land surface, infiltrates into soils, recharges groundwater, discharges into

streams, and ultimately, flows out into the oceans, from which it will eventually evaporate again. The various systems involved in the hydrological cycle are usually referred to as hydrological systems.

**(Climate change) Impacts**

The effects of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts:

- *Potential impacts*: all impacts that may occur given a projected change in climate, without considering adaptation.
- *Residual impacts*: the impacts of climate change that would occur after adaptation.

**Mitigation**

Technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to Climate Change, mitigation means implementing policies to reduce greenhouse gas emissions and enhance sinks.

**No-regrets policy**

A policy that would generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs.

**Perturbation**

A systemic disturbance resulting from a sudden shock of a magnitude beyond “normal” vulnerability (based on Turner et al. 2003).

**Projection**

A potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realised, and are therefore subject to substantial uncertainty.

**Reliability**

Reliability is defined as the likelihood that services are delivered (no failure) within a given period, expressed as a probability. High probabilities indicate high reliability (Hashimoto, T. et al., 1982b).

**Resilience**

The ability of a system to absorb perturbation or stress without changes to its fundamental structure or function that would drive the system into a different state (or to extinction) (based on Turner et al. 2003).

**Risk**

The conditional probability and magnitude of harm attendant on exposure to a perturbation or stress (based on Turner et al. 2003).

**Robustness**

The ability of a system to perform satisfactorily under a wide range of scenarios (based on Turner et al. 2003).

**Scenario**

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**

The extent to which a system or its components is likely to experience harm—and the magnitude of that harm—due to exposure to perturbation or stress (based on Turner et al. 2003).

**Stress**

Cumulative pressure on a system resulting from processes within the normal range of variability, but which over time may result in disturbances that either harm a system or otherwise move it to adjust and adapt (based on Turner et al. 2003).

**Threshold**

The level of magnitude of a system process at which sudden or rapid change occurs. A point or level at which new properties emerge in an ecological, economic or other system, invalidating predictions based on mathematical relationships that apply at lower levels.

**Uncertainty**

**A.** An expression of the degree to which a value (e.g., the future state of the *climate system*) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain *projections* of human behaviour. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgment of a team of experts.

**B.** Uncertain situations are those in which the probability of potential outcomes and their results cannot be described by objectively known probability distributions, or the outcomes themselves, or the results of those outcomes are indeterminate (USACE, 1992)

**United Nations Framework Convention on Climate Change (UNFCCC)**

The Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”. It contains commitments for all Parties. Under the Convention, Parties included in Annex I (all OECD member countries in the year 1990 and countries with economies in transition) aim to return greenhouse gas emissions not controlled by the Montreal Protocol to 1990 levels by the year 2000. The Convention entered in force in March 1994.

**Vulnerability**

The degree to which a person, system, or unit is likely to experience harm due to exposure to perturbation or stress (based on Turner et al. 2003).

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