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Africa

PAUL DESANKER (MALAWI) AND CHRISTOPHER MAGADZA (ZIMBABWE)

Lead Authors:
A. Allali (Morocco), C. Basalirwa (Uganda), M. Boko (Benin), G. Dieudonne (Niger), T.E. Downing (UK), P.O. Dube (Botswana), A. Githeko (Kenya), M. Githendu (Kenya), P. Gonzalez (USA), D. Gwary (Nigeria), B. Jallow (The Gambia), J. Nwafor (Nigeria), R. Scholes (South Africa)

Contributing Authors:
A. Amani (Niger), A. Bationo (Burkina Faso), R. Butterfield (UK), R. Chafil (Morocco), J. Feddema (The Netherlands), K. Hilmi (Morocco), G.M. Mailu (Kenya), G. Midgley (South Africa), T. Ngara (Zimbabwe), S. Nicholson (USA), D. Olago (Kenya), B. Orlando (USA), F. Semazzi (USA), L. Unganai (Zimbabwe), R. Washington (UK)

Review Editor:
I. Niang-Diop (Senegal)

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EXECUTIVE SUMMARY

Africa is highly vulnerable to the various manifestations of climate change. Six situations that are particularly important are:

- Water resources, especially in international shared basins where there is a potential for conflict and a need for regional coordination in water management
- Food security at risk from declines in agricultural production and uncertain climate
- Natural resources productivity at risk and biodiversity that might be irreversibly lost
- Vector- and water-borne diseases, especially in areas with inadequate health infrastructure
- Coastal zones vulnerable to sea-level rise, particularly roads, bridges, buildings, and other infrastructure that is exposed to flooding and other extreme events
- Exacerbation of desertification by changes in rainfall and intensified land use.

The historical climate record for Africa shows warming of approximately 0.7°C over most of the continent during the 20th century, a decrease in rainfall over large portions of the Sahel, and an increase in rainfall in east central Africa. Climate change scenarios for Africa, based on results from several general circulation models using data collated by the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Center (DDC), indicate future warming across Africa ranging from 0.2°C per decade (low scenario) to more than 0.5°C per decade (high scenario). This warming is greatest over the interior of semi-arid margins of the Sahara and central southern Africa.

Projected future changes in mean seasonal rainfall in Africa are less well defined. Under the low-warming scenario, few areas show trends that significantly exceed natural 30-year variability. Under intermediate warming scenarios, most models project that by 2050 north Africa and the interior of southern Africa will experience decreases during the growing season that exceed one standard deviation of natural variability; in parts of equatorial east Africa, rainfall is predicted to increase in December–February and decrease in June–August. With a more rapid global warming scenario, large areas of Africa would experience changes in December–February or June–August rainfall that significantly exceed natural variability.

Water: Africa is the continent with the lowest conversion factor of precipitation to runoff, averaging 15%. Although the equatorial region and coastal areas of eastern and southern Africa are humid, the rest of the continent is dry subhumid to arid. The dominant impact of global warming is predicted to be a reduction in soil moisture in subhumid zones and a reduction in runoff. Current trends in major river basins indicate a decrease in runoff of about 17% over the past decade. Reservoir storage shows marked sensitivity to variations in runoff and periods of drought. Lake storage and major dams have reached critically low levels, threatening industrial activity. Model results indicate that global warming will increase the frequency of such low storage episodes.

Natural Resources Management and Biodiversity: Land-use changes as a result of population and development pressures will continue to be the major driver of land-cover change in Africa, with climate change becoming an increasingly important contributing factor by mid-century. Resultant changes in ecosystems will affect the distribution and productivity of plant and animal species, water supply, fuelwood, and other services. Losses of biodiversity are likely to be accelerated by climate change, such as in the Afromontane and Cape centers of plant endemism. Projected climate change is expected to lead to altered frequency, intensity, and extent of vegetation fires, with potential feedback effects on climate change.

Human Health: Human health is predicted to be adversely affected by projected climate change. Temperature rises will extend the habitats of vectors of diseases such as malaria. Droughts and flooding, where sanitary infrastucture is inadequate, will result in increased frequency of epidemics and enteric diseases. More frequent outbreaks of Rift Valley fever could result from increased rainfall. Increased temperatures of coastal waters could aggrevate cholera epidemics in coastal areas.

Food Security: There is wide consensus that climate change, through increased extremes, will worsen food security in Africa. The continent already experiences a major deficit in food production in many areas, and potential declines in soil moisture will be an added burden. Food-importing countries are at greater risk of adverse climate change, and impacts could have as much to do with changes in world markets as with changes in local and regional resources and national agricultural economy. As a result of water stress, inland fisheries will be rendered more vulnerable because of episodic drought and habitat destruction. Ocean warming also will modify ocean currents, with possible impacts on coastal marine fisheries.

Settlements and Infrastructure: The basic infrastructure for development—transport, housing, services—is inadequate now, yet it represents substantial investment by governments. An increase in damaging floods, dust storms, and other extremes would result in damage to settlements and infrastructure and affect human health.

Most of Africa's largest cities are along coasts. A large percentage of Africa's population is land-locked; thus, coastal facilities are economically significant. Sea-level rise, coastal erosion, saltwater intrusion, and flooding will have significant impacts on African communities and economies.

Desertification: Climate change and desertification remain inextricably linked through feedbacks between land degradation and precipitation. Climate change might exacerbate desertification through alteration of spatial and temporal patterns in temperature, rainfall, solar insolation, and winds. Conversely, desertification aggravates carbon dioxide (CO_2)-induced climate change through the release of CO_2 from cleared and dead vegetation and reduction of the carbon sequestration potential of desertified land. Although the relative importance of climatic and anthropogenic factors in causing desertification remains unresolved, evidence shows that certain arid, semi-arid, and dry subhumid areas have experienced declines in rainfall, resulting in decreases in soil fertility and agricultural, livestock, forest, and rangeland production. Ultimately, these adverse impacts lead to socioeconomic and political instability. Potential increases in the frequency and severity of drought are likely to exacerbate desertification.

Given the range and magnitude of the development constraints and challenges facing most African nations, the overall capacity for Africa to adapt to climate change is low. Although there is uncertainty in what the future holds, Africa must start planning now to adapt to climate change. National environmental action plans and implementation must incorporate long-term changes and pursue "no regret" strategies. Current technologies and approaches—especially in agriculture and water—are unlikely to be adequate to meet projected demands, and increased climate variability will be an additional stress. Seasonal forecasting—for example, linking sea-surface temperatures to outbreaks of major diseases—is a promising adaptive strategy that will help save lives. It is unlikely that African countries on their own will have sufficient resources to respond effectively.

Climate change also offers some opportunities. The process of adapting to global climate change, including technology transfer, offers new development pathways that could take advantage of Africa's resources and human potential. Examples would include competitive agricultural products, as a result of research in new crop varieties and increased international trade, and industrial developments such as solar energy. Regional cooperation in science, resource management, and development already are increasing.

This assessment of vulnerability to climate change is marked by uncertainty. The diversity of African climates, high rainfall variability, and a very sparse observational network make predictions of future climate change difficult at the subregional and local levels. Underlying exposure and vulnerability to climatic changes are well established. Sensitivity to climatic variations is established but incomplete. However, uncertainty over future conditions means that there is low confidence in projected costs of climate change.

Improvements in national and regional data and capacity to predict impacts is essential. Developing African capacity in environmental assessment will increase the effectiveness of aid. Regional assessments of vulnerability, impacts, and adaptation should be pursued to fill in the many gaps in information.

10.1. Introduction to African Region

10.1.1. Previous Syntheses of African Region

Previous assessments (Hulme, 1996; IPCC, 1998) concluded that the African continent is particularly vulnerable to the impacts of climate change because of factors such as widespread poverty, recurrent droughts, inequitable land distribution, and overdependence on rainfed agriculture. Timely response actions were considered to be beyond the economic means of some countries. Deterioration in terms of trade, inappropriate policies, high population growth rates, and lack of significant investment—coupled with a highly variable climate—have made it difficult for several countries to develop patterns of livelihood that would reduce pressure on the natural resource base. The reports fell short of assigning relative importance to these different factors in Africa's capacity to adapt to climate change. This still is not possible and presents a new challenge for future assessments.

10.1.2. What is Different about Africa?

The main background factors that need to be kept in mind in assessing the vulnerability of the African region to climate change—particularly the capacity of African governments to respond proactively to changes that are largely not of their making or under their control—are as follows:

- *Diversity:* The term "African region" is a geographical convenience only. There is as much diversity of climate, landform, biota, culture, and economic circumstance within the region as there is between it and, say, South America or Asia. Very few statements are valid for the entire continent. The generalities that follow must be read in that context.
- *Climate:* Africa is predominantly tropical, hot, and dry. There are small regions of temperate (cool) climates in the extreme south and north and at high altitudes in between. Parts of west Africa, as well as the western part of central Africa, are humid throughout the year. A large region north and south of this humid core is subhumid, with substantial rainfall during the wet season (or seasons, in the case of east Africa) but almost no rain during the extended dry season. Poleward from this zone is a large area of semi-arid climates, which permit marginal cropping during the wet season but are characterized by extreme unreliability of rainfall and few permanent surface-water sources. Most of the human population occurs in the subhumid and semi-arid zones. Corresponding to the tropics of Capricorn and Cancer are the vast desert regions of the Kalahari-Namib and the Sahara.
- *Development Status:* Measured by almost any index of human well-being, Africa contains the poorest and least-developed nations of the world. Per capita gross domestic product (GDP), life expectancy, infant mortality, and adult literacy are all in the bottom quartile globally when averaged across Africa, although individual nations may perform somewhat better on one or more of these indices. The general weakness of the science and technology infrastructure—in particular, the relatively small numbers of technically trained professionals—limits the rate at which adaptive research can be performed or implemented.
- *Food Supply:* More than half of the African population is rural and directly dependent on locally grown crops or foods harvested from the immediate environment. Per capita food production in Africa has been declining over the past 2 decades, contrary to the global trend. The result is widespread malnutrition, a recurrent need for emergency food aid, and increasing dependence on food grown outside the region.
- *Dependence on Natural Resources:* The formal and informal economies of most African countries are strongly based on natural resources: Agriculture, pastoralism, logging, ecotourism, and mining are dominant. Climatic variations that alter the viability of these activities, for better or for worse, have very high leverage on the economy.
- *Biodiversity:* About one-fifth of the world's plants, birds, and mammals originate or have major areas of present conservation in Africa. There are major "hot spots" of biodiversity within west, east, central, and southern Africa.
- *Low Capacity for State-Initiated Interventions:* Governance structures typically are underfunded and undercapacity. In many instances they have been undermined by military coups, despotism, tribalism, corruption, maladministration, and economic adjustment programs imposed by the international financial community. Communication from capitals to the remotest provinces—by road, rail, air, or telephone—often is unreliable and slow. State-centered political economies in their postcolonial sense are relatively recent over most of Africa, and their boundaries include wide ethnic diversity within single nations and cut across previous political territories.
- *Disease Burden:* Insect-vector diseases such as malaria and tryanosomiasis; water-borne diseases such as typhoid, cholera, and schistosomiasis; and poverty-related diseases such as tuberculosis are prevalent in Africa. Water and food security are closely linked with health. The HIV/AIDS pandemic is placing great strain on the health infrastructure. Heavy mortalities lead to great loss of productive potential.
- *Armed Conflict:* There has been chronic armed conflict in several regions of Africa almost continuously for the past 3 decades. This weakens the ability of the nations involved to respond to climate change and adds large refugee populations to the local population, which must be supported by the environment.
- *High External Trade and Aid Dependence:* Very little industrial beneficiation takes place in Africa. High volumes of relatively low-value goods dominate export economies. In general, there is no strong internal demand

(national or regional) to buffer the economies from changes in global trade. Trade linkages show the pattern established by the former colonial relationships. Many African countries have a negative trade balance, particularly as a result of heavy international debt-servicing burdens, and are chronically dependent on financial aid from the developed world.

10.1.3. Past to Present

10.1.3.1. Climatology

Africa is a vast continent, and it experiences a wide variety of climate regimes. The location, size, and shape of the African continent play key roles in determining climate. The poleward extremes of the continent experience winter rainfall associated with the passage of mid-latitude airmasses. Across the Kalahari and Sahara deserts, precipitation is inhibited by subsidence virtually throughout the year. In contrast, moderate to heavy precipitation associated with the Inter-Tropical Convergence Zone (ITCZ) characterizes equatorial and tropical areas. Because the movement of the ITCZ follows the position of maximum surface heating associated with meridional displacement of the overhead position of the sun, near-equatorial regions experience two rain seasons, whereas regions further poleward experience one distinct rainfall season. The mean climate of Africa is further modified by the presence of large contrasts in topography (Semazzi and Sun, 1995) and the existence of large lakes in some parts of the continent.

10.1.3.2. Interannual and Interdecadal Climate Variability

Humans have adapted to patterns of climate variability through land-use systems that minimize risk, with agricultural calendars that are closely tuned to typical conditions and choices of crops and animal husbandry that best reflect prevailing conditions. Rapid changes in this variability may severely disrupt production systems and livelihoods. Interannual variability of the African climate is determined by several factors. The El Niño-Southern Oscillation (ENSO) is the most dominant perturbation responsible for interannual climate variability over eastern and southern Africa (Nicholson and Entekhapi, 1986). The typical rainfall anomaly associated with ENSO is a dipole rainfall pattern: Eastern Africa is in phase with warm ENSO episodes, whereas southern Africa is negatively correlated with these events (Nicholson and Kim, 1997). The 1997–1998 ENSO event resulted in extreme wet conditions over eastern Africa (see Boxes 10-1 and 10-2), and the 1999–2000 La Niña may have caused devastating floods in Mozambique. Modeling exercises indicate that climate change may increase the frequency of ENSO warm phases by increasing the warm pool in the tropical western Pacific or by reducing the efficiency of heat loss (Trenberth and Hoar, 1997; Timmerman *et al.*, 1999).

In the Sahel and similar regions of west Africa, the problem is more complex. ENSO appears to influence year-to-year variations and reduces rainfall. Its influence appears to be greater within long dry intervals in the Sahel, but it is not the dominant factor controlling rainfall in this region (Ward, 1998).

Over northern Africa, the North Atlantic Oscillation (NAO) is a key factor that is responsible for interannual variability of the climate (Lamb, 1978). Across western Africa, year-to-year changes in seasonal climatic conditions are determined primarily by the Atlantic Ocean, although the rest of the world's oceans also play important roles. Low-lying islands and coastal regions receive significant amounts of rainfall from tropical cyclone activity, which is sensitive to interannual variability of SST conditions over adjacent ocean basins.

Box 10-1. The 1997–1998 ENSO Event

ENSO appears to play a major role in east Africa, but it masks the perhaps more important role of the other oceans, particularly the Indian Ocean. The 1961–1962 rains were spectacularly manifested as rapid rises in the levels of east African lakes. Lake Victoria rose 2 m in little more than a year (Flohn and Nicholson, 1980). This was not an ENSO year, but exceedingly high sea-surface temperatures (SSTs) occurred in the nearby Indian Ocean as well as the Atlantic. Such high SSTs are associated with most ENSO events, and it is probably SSTs in these regions, rather than the Pacific ENSO (Nicholson and Kim, 1997), that have the largest influence on east African rainfall. In another example, the dipole pattern anticipated to occur during ENSO events did not occur during the 1997–1998 event. There was a tremendous increase in rainfall in east Africa, but intense drought conditions did not occur throughout southern Africa. The reason appears to be an unusual pattern of SST in the Indian Ocean.

Box 10-2. Drought Conditions in the Sahel

One of the most significant climatic variations has been the persistent decline in rainfall in the Sahel since the late 1960s. The trend was abruptly interrupted by a return of adequate rainfall conditions in 1994. This was considered to be the wettest year of the past 30 and was thought to perhaps indicate the end of the drought. However, by the standard of the whole century, rainfall in 1994 barely exceeded the long-term mean. Also, the 1994 rainy season was unusual in that the anomalously wet conditions occurred toward the end of the rainy season and in the months following. Unfortunately, dry conditions returned after 1994. The persistent drying trend has caused concern among development planners regarding how to cope with losses of food production, episodes of food insecurity, displacements of populations, lack of water resources, and constraints on hydroelectricity.

The climate of Africa also exhibits high interdecadal variability. Rainfall variability in the Sahel derives from factors such as SST and atmospheric dynamics (Lamb, 1978; Folland *et al.*, 1986; Hulme and Kelly, 1997; Nicholson and Kim, 1997) and is modulated by land surface effects related to soil moisture, vegetation cover, dust, and so forth (Charney, 1975; Diedhiou and Mahfouf, 1996; Xue, 1997; Zeng *et al.*, 1999). Modeling evidence also suggests that orographic control plays a significant role in promoting climate teleconnections between global SST anomalies and west African interannual climate variability (Semazzi and Sun, 1997).

Besides ENSO, the NAO, and west African climate anomaly patterns, other continental-scale and subcontinental climate anomalies play significant roles in determining interannual and longer climate variability time scales (Nicholson *et al.*, 2000). For instance, the decade 1950–1959 was characterized by above-normal precipitation over most of Africa, although rainfall deficiencies prevailed over the near-equatorial region. Later, during the period 1960–1969, this rainfall anomaly pattern dramatically reversed in sign, with rainfall deficits observed for most of Africa while the equatorial region experienced widespread abundance of rainfall. These two time periods also coincide with a reversal in the sign of the Sahelian rainfall anomalies (Lamb and Peppler, 1992). More recently, the pattern has been one of increased aridity throughout most of the continent. Mean rainfall decreased by 20–49% in the Sahel between the periods 1931–1960 and 1968–1997 and generally 5–10% across the rest of the continent (see Figure 10-1).

In comparison with the period between 1950 and 1970, the average length of the rainy season has not changed significantly during the dry period 1970–1990. Instead, the decrease in rainfall in July and August explains most of the diminution of total annual rainfall over the Sahel since 1970. The average number of rainy events in August was reduced by about 30% (Le Barbé and Lebel, 1997).

There is emerging evidence that aerosols and dust also may be important factors in modulating the variability of the African climate (d'Almeida, 1986; Mohamed *et al.*, 1992; Pinker *et al.*, 1994). These studies provide overwhelming evidence of an extremely dense and deep (reaching up several kilometers) dust layer in the Sahel/Sudan during the main dust season from November to April.

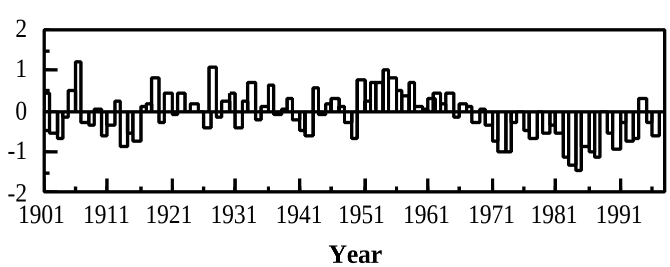

Figure 10-1: Rainfall fluctuations, 1901–1998, expressed as regionally averaged standard deviation (departure from long-term mean divided by standard deviation) for the Sahel.

10.1.3.3. Paleoclimate of Africa

Paleoclimatology and paleoenvironmental changes in Africa have been reconstructed from several lines of sedimentary evidence, such as fossil strand lines, diatom and pollen analyses, evidence of glaciation and fossil moraines on high mountains, sediment lithology, geochemistry and biogeochemistry, and so forth. Most records do not extend beyond 30,000 years before the present (BP), but they capture the climatic extremes of the last glacial-interglacial cycle—the last glacial maximum (22,000 to 14,000 years BP) through to the Holocene period (10,000 years BP to present) (Olago, 2001).

Temperatures during the last glacial maximum are estimated to have been 4–7°C lower than today, and they were coupled with intensive aridity and regression of lakes throughout the African continent, resulting from reduced precipitation as a consequence of weaker monsoons, stronger dry trade winds, and lowered SST (Coetzee, 1967; Flenley, 1979; COHMAP Members, 1988; Bonnefille *et al.*, 1990; Vincens *et al.*, 1993). Highland vegetation was depressed to significantly lower altitudes relative to today, and mountain glaciers were at their maximum extent. Grasslands were more widespread, lowland forests became fragmented, and subtropical desert margins advanced latitudinally by 300–700 km relative to their present positions (Flohn and Nicholson, 1980).

During the Holocene period of the past 10,000 years there was a "warm" climatic optimum roughly 5,000 years ago. At that time, more humid conditions generally were widespread, and deserts were markedly contracted. Lakes existed even in parts of the central Sahara. The current state of climate was reached roughly 3,000 years ago.

10.1.3.4. Recent Historical Record

Observational records show that the continent of Africa is warmer than it was 100 years ago (IPCC,1996). Warming through the 20th century has been at the rate of about 0.05°C per decade (see Figure 10-2), with slightly larger warming in the June, July, August (JJA) and September–November seasons than in December, January, February (DJF) and March–May (Hulme *et al.*, 2001). The 5 warmest years in Africa have all occurred since 1988, with 1988 and 1995 the two warmest years. This rate of warming is not dissimilar to that experienced globally, and the periods of most rapid warming—the 1910s to 1930s and the post-1970s—occur simultaneously in Africa and the world.

The climate of Africa has experienced wetter and drier intervals during the past 2 centuries. The most pronounced periods were during the 20th century. A very intense dry period, much like the current one, also prevailed for 2 to 3 decades during the first half of the 19th century. Humid conditions reminiscent of the 1950s prevailed around the 1870s or 1880s, but another milder arid interval of roughly 20 years commenced around 1895.

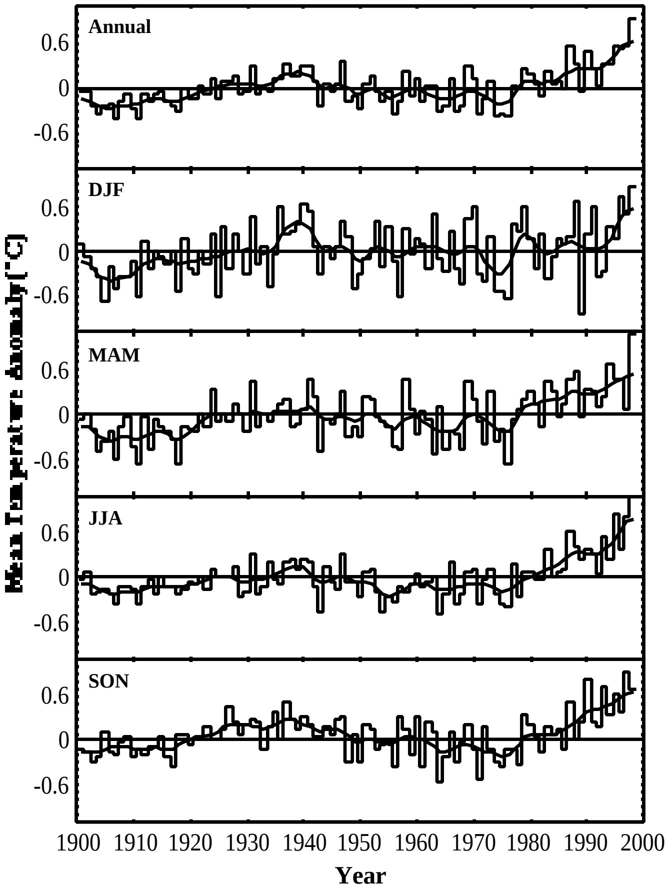

Figure 10-2: Mean surface air temperature anomalies for the African continent, 1901–1998, expressed with respect to 1961–1990 average, annual and four seasons (DJF, MAM, JJA, SON). Smooth curves result from applying a 10-year Gaussian filter.

10.1.4. Climate Change Scenarios

Carter *et al.* (2000) performed a comprehensive characterization of regional climate change projections for the 21st century. They assumed a range of atmospheric greenhouse gas (GHG) loadings according to the four draft marker scenarios developed for the IPCC *Special Report on Emissions Scenarios* (SRES), in combination with the IPCC range of climate sensitivities (1.5–4.5°C—IPCC, 1996). Their method of analysis involved combining simple climate model estimates of the global mean annual temperature response to four combinations of GHG forcing/climate sensitivity (see Table 3-9) with regional patterns of seasonal temperature and precipitation change obtained from 10 general circulation model (GCM) simulations for the end of the 21st century relative to 1961–1990. The GCM patterns of change were scaled up or down so that the global mean temperature change from the GCM coincided with that obtained from the simple climate model. Ten patterns of change were obtained for each emissions/climate sensitivity combination, and each was averaged over subcontinental regions, including five representing the African continent: southern Europe/north Africa, the Sahara, west Africa, east Africa, and southern Africa (Carter *et al.*, 2000; see Chapter 3). Ranges of projected rates of change in temperature and precipitation over these regions are depicted for each season, and projected changes over southern Africa by the 2050s are compared with modeled natural multi-tridecadal variability from the HadCM2 GCM 1,400-year control simulation (Tett *et al.*, 1997) for the summer (DJF) and winter (JJA) months.

An analysis using the similar methodology also has been conducted specifically for Africa (Hulme *et al*., 2001). Future annual warming across Africa ranges from 0.2°C per decade (B1—low scenario) to more than 0.5°C per decade (A2—high scenario). This warming is greatest over the interior of semi-arid margins of the Sahara and central southern Africa. The intermodel range (an indicator of the extent of agreement between different GCMs) is smallest over north Africa and the equator and greatest over the interior of southern Africa.

Future changes in mean seasonal rainfall in Africa are less well defined. Under the lowest warming scenario, few areas experience changes in DJF or JJA that exceed two standard deviations of natural variability by 2050. The exceptions are parts of equatorial east Africa, where rainfall increases by 5–20% in DJF and decreases by 5–10% in JJA.

Under the two intermediate warming scenarios, significant decreases (10–20%) in rainfall during March to November, which includes the critical grain-filling period, are apparent in north Africa in almost all models by 2050, as are 5–15% decreases in growing-season (November to May) rainfall in southern Africa in most models.

Under the most rapid global warming scenario, increasing areas of Africa experience changes in summer or winter rainfall that exceed the one sigma level of natural variability. Large areas of equatorial Africa experience increases in DJF rainfall of 50–100% over parts of eastern Africa, with decreases in JJA over parts of the Horn of Africa. However, there are some JJA rainfall increases for the Sahel region.

Hulme *et al.* (2001) also analyzed future rainfall changes for three African regions—the Sahel, east Africa, and southeast Africa—to illustrate the extent of intermodel differences for these regions and to put future modeled changes in the context of past observed changes (see Figure 10-3). Although model results vary, there is a general consensus for wetting in East Africa, drying in southeast Africa, and a poorly specified outcome for the Sahel.

10.2. Key Regional Concerns

10.2.1. Water Resources

10.2.1.1 Overview of Regional Water Resources

Water resources are inextricably linked with climate, so the prospect of global climate change has serious implications for water resources and regional development (Riebsame *et al.*,

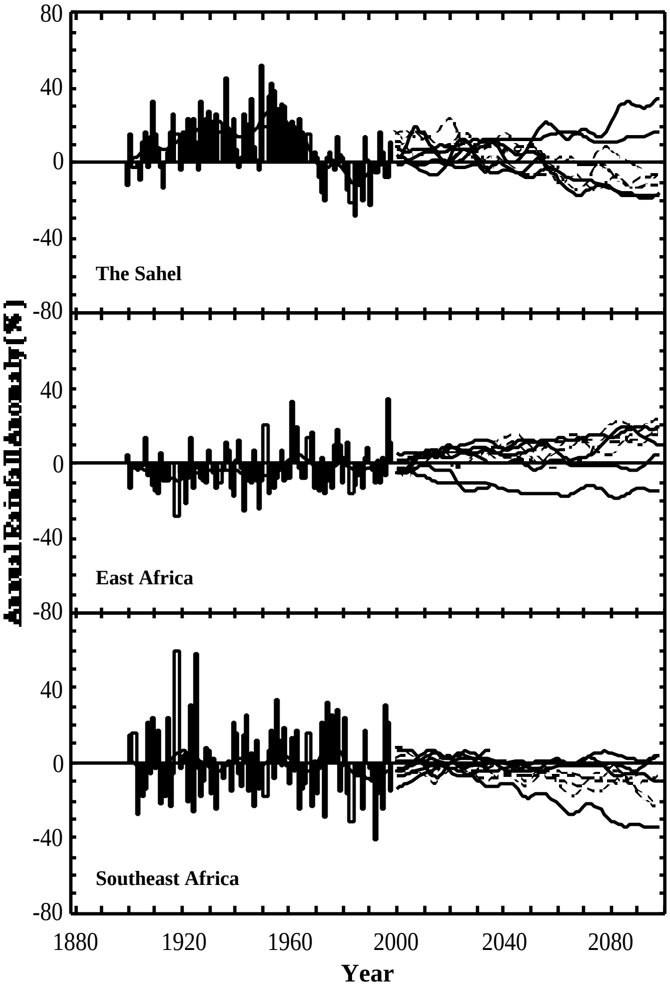

Figure 10-3: Observed annual rainfall anomalies for three African regions, 1900–1998, and model-simulated anomalies for 2000–2099. Model anomalies are for 10 model simulations derived from seven DDC GCM experiments; the four HadCM2 simulations are the dashed curves. All anomalies are expressed with respect to observed or model-simulated 1961–1990 average rainfall. Model curves are extracted directly from GCM experiments, and results are not scaled to SRES scenarios used in Chapter 3. Smooth curves result from applying a 20-year Gaussian filter (Hulme *et al*., 2001).

1995). Efforts to provide adequate water resources for Africa will confront several challenges, including population pressure; problems associated with land use, such as erosion/siltation; and possible ecological consequences of land-use change on the hydrological cycle. Climate change—especially changes in climate variability through droughts and flooding—will make addressing these problems more complex. The greatest impact will continue to be felt by the poor, who have the most limited access to water resources.

Figure 10-4 shows that the hydrological performance of Africa results in much less runoff yield than in other regions. Apart from the Zambezi/Congo Rivers, the major African rivers (Nile, Niger, Senegal, Senqu/Orange, Rufiji) traverse semi-arid to arid lands on their way to the coast. Of the world's major rivers, the Nile has the lowest specific discharge (i.e., flow per unit catchment area), even if only the part of the catchment that receives precipitation is considered (Reibsame *et al.,* 1995). Furthermore, because these major rivers originate within the tropics, where temperatures are high, evaporative losses also are high in comparison to rivers in temperate regions. Elevated temperatures will enhance evaporative losses; unless they are compensated by increased precipitation, runoff is likely to be further reduced.

In Morocco, the northward displacement of the Azores high-pressure cell is a subject of study because of its asscociation with a drought cycle that is related to the dipole between the positioning of the Azores high-pressure cell and the Iceland low-pressure cell. These severe droughts seem to manifest themselves in Morocco in periodicities varying between 2 and 13 years (Stockton and Allali, 1992).

The Magreb region is characterized by erratic and variable rainfall, with a high rate of evapotranspiration (almost 80%). In addition, the Magreb region will have water scarcity by 2025, especially in Tunisia and Libya.

Associated with the poor hydrological performance of African river basins is the fact that most of the lakes in Africa have a delicate balance between precipitation and runoff; all of the

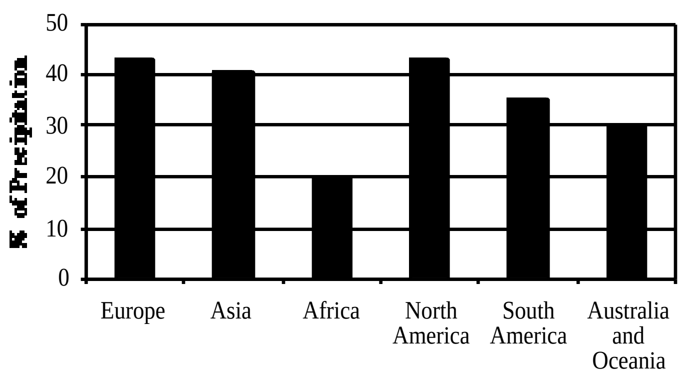

Figure 10-4: Comparative hydrology in world regions—total runoff as percentage of precipitation (GEMS, 1995).

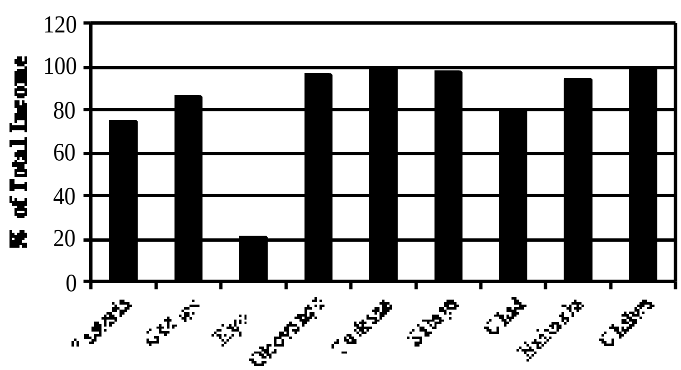

Figure 10-5: Evaporative losses as percentage of total hydrological income in selected African lakes (constructed from Talling and Lemoalle, 1998).

Table 10-1*: Estimates of ranges of percentage changes in precipitation, potential evaporation, and runoff in African river basins, constructed from Figure 3 of Arnell (1999). In some basins, estimates given by HadCM3 simulation have been excluded where they appear to be outliers.*

Basin	Change in Precipitation (%)	Change in Potential Evaporation (%)	Change in Runoff (%)
Nile	10	10	0
Niger	10	10	10
Volta	0	4 to -5	0 to -15
Schebeli	-5 to 18	10 to 15	-10 to 40
Zaire	10	10 to 18	10 to 15
Ogooue	-2 to 20	10	-20 to 25
Rufiji	-10 to 10	20	-10 to 10
Zambezi	-10 to -20	10 to 25	-26 to -40
Ruvuma	-10 to 5	25	-30 to -40
Limpopo	-5 to -15	5 to 20	-25 to -35
Orange	-5 to 5	4 to 10	-10 to 10

large lakes show less than 10% runoff-to-precipitation ratio (Talling and Lemoalle, 1998), and important water basins like Lake Chad and the Okavango Delta have no outflow because evaporation and permiation balance runoff (see Figure 10-5).

In the savanna regions, the incidence of seasonal flow cessation may be on the increase, as shown by some streams in Zimbabwe (Magadza, 2000). Drought periods now translate into critical water shortages for industrial and urban domestic supplies (Magadza, 1996).

10.2.1.2. Major River Basin Systems

The heterogeneity of ground records in Africa imposes serious limitations in constructing future scenarios of water resources. Where consistent long-term climatic data are available, they indicate a trend toward reduced precipitation in current semi-arid to arid parts of Africa. Figure 10.3 of the Hulme *et al.* (2001) publication shows possible scenarios for different climatic regions of Africa. Although there is ambiguity in the Sahel, the simulations appear to indicate possible increases in precipitation in east Africa, whereas most simulations in southern Africa indicate reduced precipitation in the next 100 years.

Table 10-1 shows estimates of ranges of percentage changes in precipitation, potential evaporation, and runoff in African river basins as reconstructed from Arnell (1999, Figure 3). In some basins, estimates given by the HadCM3 simulation have been excluded where they appear to be outliers. A change in the hydrographs of large basins (Niger, Lake Chad, and Senegal) has been observed. Between the mean annual discharge of the humid and drought periods, the percentage of reduction varies from 40 to 60% (Olivry, 1993). Figure 10-6 shows the change in the hydrograph of the Niger River at the Niamey station. This illustrates a clear modification of the Niger River regime at Niamey. Similar situations are observed at the N'djamena station on the Chari at the entrance to Lake Chad. In the Nile basin, Sircoulon (1999) cites a reduction in runoff of 20% between 1972 and 1987, corresponding to a general decrease in precipitation in the tributary basins calculated by Conway and

Box 10-3. Impact of Drought in the Akasompo Dam (Graham, 1995)

Multiple droughts in recent decades have forced Ghana to reduce the generation of hydroelectricity, provoking a national debate about power supply.

The Akosombo and Kpong generating stations—commissioned in 1965 and 1982, respectively—provide the overwhelming bulk of Ghana's electricity. The two stations account for 1,072 MW of a total national power-generating capacity of 1,160 MW; Akosombo alone provides 833 MW.

Until recently, most of the minority of Ghanaians who use electricity tended to regard the Volta hydroelectric dams as sources of uninterruptible power. The unprecedented drought of 1982–1983, which compelled rationing of electricity until 1986, shattered that illusion. And if that drought's power cuts jolted the nation's complacency about hydroelectricity, the 1994 incident concentrated minds forcefully on the impermanence of power from Akosombo and Kpong and the need for alternative sources.

According to the Volta River Authority (VRA), the statutory power generating body, "cumulative inflow" into Volta Lake by the middle of August 1994 was "the worst…in the 50-year record of Volta river flows—worse than the same period in 1983." At its lowest, in early August, the level of Volta Lake was 73 m. This was well below the 75.6 m the VRA claims is the minimum level for generating power without risk of damaging the turbines.

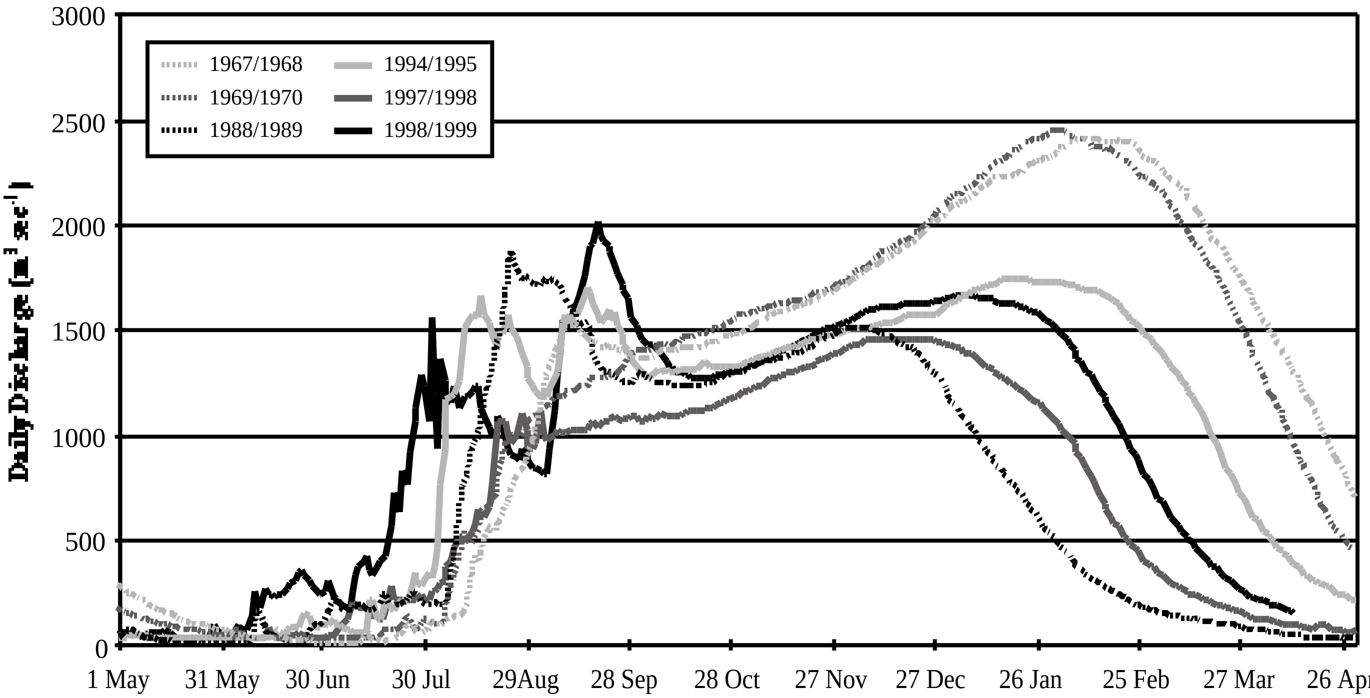

Figure 10-6: Decadal changes in hydrograph of the Niger River at Niamey Station between 1961 and 1999.

Hulme (1993). In recent years there have been significant interruptions in hydropower generation as a result of severe droughts (see Box 10-3).

Instrumental data and climate model simulations cited above indicate imminent water crisis in large parts of Africa. Several seminal works have appeared in the literature that analyze water for Africa, including Falkenmark (1989) and Gleick (1992, 1998).

Large basin-scale analyses often give the wrong impression that many areas of Africa are rich in water reserves, in which case local water problems could be solved easily by technology that would transfer water from the source to areas under stress, assuming that financial resources are available for such enterprises. Although in theory this may be a practical solution to many water problems in most of Africa, the very high costs associated with such projects make them impractical. Political goals such as self-sufficiency in food production and general socioeconomic development cannot be achieved under severe water scarcity (Falkenmark, 1989). Drought-prone zones of Africa already are water-limited, further increasing their vulnerability to water problems.

About 63% of the total land in Africa lies within transboundary river basins. Five major river basins—the Congo, Nile, Niger, Chad, and Zambezi—occupy about 42% of the geographical area and sustain more than 44% of the African population. Other shared basins in the continent are the Senegal, Gambia, Limpopo, Orange/Senqu, and Cunene Basins.

In west Africa, the dependency ratio—defined as the ratio between renewable water produced out of a country and the total renewable water of the same country—is more than 40% for seven of the nine countries comprising the Permanent Interstate Committee for Drought Control in the Sahel (CILSS). This ratio is nearly 90% for the Niger and the Mauritania. Similar transboundary dependencies are evident in southern Africa and on the Nile basin. The Congo basin is shared by the most countries (13), followed by the Niger and Nile basins (11 countries each) and the Zambezi and Chad basins (9 and 8 countries, respectively).

The impact of changes in precipitation and enhanced evaporation could have profound effects in some lakes and reservoirs. Conway and Hulme (1993) and Calder *et al*. (1995) have discussed the hydrology and paleohydrology of various African Lakes. Magadza (1996) has examined the impact of drought on reservoirs in Zimbabwe. Reports fron Ghana (Graham, 1995) indicate severe drought impacts on this large reservoir. Studies show that, in the paleoclimate of Africa and in the present climate, lakes and reservoirs respond to climate variability via pronounced changes in storage, leading to complete drying up in many cases. Furthermore, these studies also show that under the present climate regime several large lakes and wetlands show a delicate balance between inflow and outflow, such that evaporative increases of 40%, for example, could result in much reduced outflow. In the case of Lake Malawi, it has been reported that the lake had no outflow for more than a decade in the earlier part of this century (Calder *et al*., 1995).

Predictions of response by the Nile to global warming are confounded by the fact that different simulations give conflicting results (Smith *et al.*, 1995), varying from 77% flow reduction in the Geophysical Fluid Dynamics Laboratory (GFDL) simulation to a 30% increase in the Goddard Institute for Space Studies

(GISS) model. Arnell's (1999) model results suggest increased precipitation in the Nile basin, but such gains are offset by evapotranspiration. Gleick (1992) projects that future climatic changes in the Nile basin would be significant and possibly severe. The response of the Nile basin to precipitation change is not linear, though it is symmetric for increased and decreased precipitation. Hulme (1992) shows a decline in total precipitation and overall warming of about 0.5°C over the last half on the 20th century. Conway and Hulme (1993) conclude that the effects of future climate change on Nile discharge would further increase uncertainties in Nile water planning and management, especially in Egypt. Nile precipitation responds more to changes in equatorial circulation, with little influence by the north African monsoon (Sestini, 1993).

Arnell (1999) shows that the greatest reduction in runoff by the year 2050 will be in the southern Africa region, also indicating that as the water use-to-resource ratio changes countries such as Zimbabwe and the Magreb region will shift into the high water-stress category. The Zambezi River has the worst scenario of decreased precipitation (about 15%), increased potential evaporative losses (about 15–25%), and diminished runoff (about 30–40%).

Lake Chad varies in extent between the rainy and dry seasons, from 50,000 to 20,000 km^2. Precise boundaries have been established between Chad, Nigeria, Cameroon, and Niger. Sectors of the boundaries that are located in the rivers that drain into Lake Chad have never been determined, and several complications are caused by flooding and the appearance or submergence of islands. Asimilar process on the Kovango River between Botswana and Namibia led to a military confrontation beteen the two states.

Vorosmarty and Moore (1991) have documented the potential impacts of impoundment, land-use change, and climatic change on the Zambezi and found that they can be substantial. Cambula (1999) has shown a decrease in surface and subsurface runoff of five streams in Mozambique, including the Zambezi, under various climate change scenarios. For the Zambezi basin, simulated runoff under climate change is projected to decrease by about 40% or more.

Growing water scarcity, increasing population, degradation of shared freshwater ecosystems, and competing demands for shrinking natural resources distributed over such a huge area involving so many countries have the potential for creating bilateral and multilateral conflicts (Gleick, 1992). Feddema (1998, 1999) has evaluated the impacts of soil degradation and global warming on water resources for Africa. All major watersheds are affected by global warming; although the trend is toward drying in most locations, there are significant differences in watershed-level responses, depending on timing and distribution of rainfall, as well as soil water-holding capacity. Soil water-holding capacity is modified by the degree of soil degradation.

10.2.1.3. Demography and Water Resources

Availability of water in sub-Saharan Africa (SSA) is highly variable. Only the humid tropical zones in central and west Africa have abundant water. Water availability varies considerably within countries as well, influenced by physical characteristics and seasonal patterns of rainfall. According to Sharma *et al.* (1996), eight countries were suffering from water stress or scarcity in 1990; this situation is getting worse as a consequence of rapid

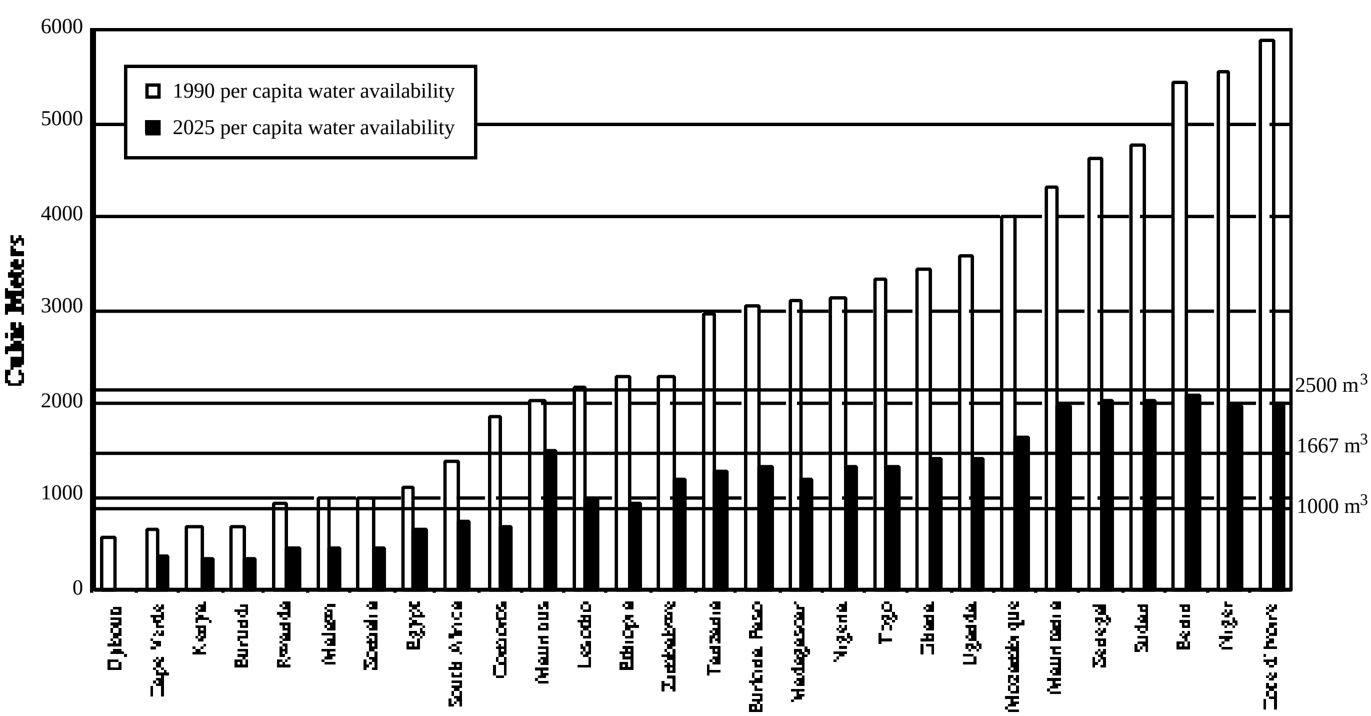

Figure 10-7: Water scarcity and people in Africa (Sharma *et al*., 1996).

population growth, expanding urbanization, and increased economic development. By 2000, about 300 million Africans risk living in a water-scarce environment. Moreover, by 2025, the number of countries experiencing water stress will rise to 18—affecting 600 million people (World Bank, 1995). Figure 10-7 shows how countries will shift from water surplus to water scarcity as a result of population changes alone between 1990 and 2025, using a per capita water-scarcity limit of 1,000 m^3 yr^{-1}. Scarcity statistics also can be associated with challenges to international water resources: Many such basins face water stress or scarcity (Sharma *et al.*, 1996). Long-term precipitation records from the Sahara give a clear indication of declining precipitation in that region (UNEP, 1997). These declines in precipitation register as reduced hydrological discharges in major river basins in the subhumid zones.

Given the climate scenarios discussed in this report, it is apparent that several countries will face water availability restrictions by the middle of the 21st century, if current consumption trends persist. Pottinger (1997) discusses some concerns about future water availability in South Africa. These examples show that the combination of demographic trends and climate change is likely to cause economically significant connstraints in some parts of Africa.

10.2.1.4. Impacts and Vulnerability

Sensitivity analyses of major rivers of the continent indicate that these rivers are sensitive to climate change. Magadza (1996) examined changes in water storage in Zimbabwe's main water storage facilities during the 1991–1992 drought cycle. During this period, the mean temperature averaged 2°C above the long-term seasonal mean, and seasonal Penman evaporation exceeded the long-term seasonal mean by more than 30%—peaking at just less than 90% in February at the Kutsaga station. During this drought cycle, stored water resources dwindled to less than 10% of installed capacity.

Urbiztondo (1992) simulated the response of Lake Kariba power-generating capacity to various climate change scenarios. His results indicate that with no significant change in precipitation, the lake would regulary fail to meet installed generating capacity if the temperature rose by 4°C. During dry years, generating capacity would decrease by as much as 50%. Even during wet years, maximum generating capacity would barely exceed 50% of installed capacity.

Economic impacts from curtailment of hydropower generation from Lale Kariba, as a result of the 1991–1992 drought, were estimated to be US$102 million loss in GDP, US$36 million loss in export earnings, and loss of 3,000 jobs (Benson and Clay, 1998). The direct impacts on agriculture and the knockon impacts also were quite severe. These limited estimates provide a window on potential economic impacts of climate change-mediated water resources changes in the medium term (i.e., into the middle of the 21st century—a time span within the planning window of economic development strategies).

With an estimated error of about 8%, the Gambia River flow has been shown to be very sensive to climate change. Based on the results of river flow responses and vulnerability analysis, climate variables alone can cause a 50% change in runoff in the Gambia River catchment (Jallow *et al.*, 1999). In general, a 1% change in rainfall will result in a 3% change in runoff (Manneh, 1997). On the whole, this translates into saltwater intrusion into the Gambia River by 40 km at times of maximum intrusion. However, the flushing action of freshwater flow of the river will keep the saline/freshwater interface at an equilibrium, oscillating between 90 and 290 km. The rate of saline water intrusion during dry seasons would increase from about 20 km per month in January to about 40 km per month in April and May.

10.2.1.5. Adaptation

Likely changes in precipitation and discharge regimes call for a wide range of adaptations. Broadly, these adaptations would include:

- Refinement of early warning sytems to enable timely remedial measures
- Shared basin management, necessitating international agreements
- Water-use strategies—especially demand management—in industry, settlements, and agriculture
- Intensified monitoring to improve data reliability
- Intensive research into energy usage and alternate renewable energy at household and industrial levels
- Intensive research into design of infrastructure facilities, such as roads and telecommunications, to withstand extreme events
- Intensive research into flood control management technology
- Innovation in building designs (e.g., to minimize urban flooding)
- Research into and commencement of coastal defense facilities
- Research into adaptive agricultural startegies
- Reserarch into environmental flow requirements.

Although there are now subregional climate change scenarios for the African region, the quality of such scenarios varies with the intensity of historical data and the spatial distribution of monitoring stations. There is an urgent need to intensify the density of monitoring stations to improve climate change scenarios. The cost of rehabilitating stations that are in disrepair is not beyond the financial capability of African states. Appreciation of the strategic importance of these facilities and a sense of ownership of climate change concerns needs to be reawakened.

It has been noted that practically all of the major river basins of Africa include several states. In recognition of this fact, the past decade has seen the development of international river basin mangement protocols—such as the Southern Africa

Development Community (SADC) Protocol on Shared Waters, the Niger Basin Authority, and several others, including the more recent Lake Victoria Fisheries Authority. The United Nations Environment Programme International Environmental Technology Center (UNEP-ITEC) have emphasized the river basin as the fundamental unit of management (UNEP, 2000). We recommend that these international basin authorities be strengthened in terms of finance and human resources and that their perspectives should embrace near- and long-term climate variability and climate change issues in their work plans. Most important is that the legal framework for such river basin authorities should be robust to ensure equity in access to and accountability for water supply and water quality management. Failure to take these concepts on board could lead to water resources-related conflict.

In general, the African continent lacks technical strategies to optimize water resources. A few countries (e.g., South Africa and Zimbabwe) have begun to develop strategies for optimum use of water resources—using, for example, water pricing and demand management tools. Crop-watering technology is primitive and wasteful in most cases. Few industrial and household water-usage strategies incorporate water reuse. During drought periods, management authorities have resorted to supply restrictions, such as the 3-day supply per week in Mutare during the 1991–1992 drought. Water supply shortages conventionally are addressed through construction of more impoundments. Magadza (1996) remarks that in severe drought periods there would be a multiple failure syndrome of water storage facilities, especially where individual reservoirs are dedicated to defined communities. Although supply structures (banning of garden hoses) and construction of storage reservoirs are practical options, demand management—which reduces consumption per unit of product output—has proved increasingly to be a water-saving strategy that can allow communities to enter a drought cycle with adequate supplies.

Whatever strategies are adopted for optimizing water usage, successful development of such strategies is contingent on reliable meteorological and hydrological information. In many instances, application of hydrological models on a basin-wide scale is restricted by data density. Reliable impacts assessments and near-term predictions depend on robust databases. For example, flood propagation and thus flood warning capability, which are real-time processes, are a function of the density of measuring points. Similarly, crop yield forecasts could be made spatially more accurate by improving the intensity of climatic measurements.

Over the past half-century, Africa has invested heavily in hydroelectric power schemes. Recent drought episodes and demand escalation have highlighted the vulnerability of even the largest hydroelectric plants to climate variability (Magadza, 1996). This assessment has shown that future water resources, especially in the subhumid to semi-arid regions of the African savanna and subtropics, will be more restricted. Research into other forms of renewable energy and energy-use efficiency in industry and households is an essential inverstment in a more energy-secure future. At the regional level, energy resource sharing is a necessary strategy. Individual states must have trust and confidence to invest in neighboring countries for overall regional energy security.

Populations that live in flood-prone areas need to consider strategies for early warning procedures for flood events; strategic planning in the location of human habitations to minimize flood impacts; and strategies for robust protocols for alleviating impacts of drought events to minimize loss of human life, economic assets, and societal norms. On the other hand, early warning systems can be effective if impacted areas are accessible in the worst-case scenario, to enable either evacuation or relief supplies delivery.

Although there are major reservoirs on most large African river basins, these reservoirs were not designed for flood control. However, synchronization of operations of reservoirs that are located in the same basin can alleviate flood impacts. Nevertheless, there is a need to consider purposely building flood control facilities in some of the flood-prone areas of Africa, similar to those found on the Danube, which reduce flood crest intensity by sequestering floodwaters into temporary storage facilities along the river. This could be a subject of directed research for each African basin.

Research into coastal defense systems is an immediate need. Several African coastal areas already are experiencing sigificant coastal impacts. Coastal management infrastructures are likely to entail intergenerational investment programs in which each extent generation must make its contribution to minimize long-term costs. If our generation abrogates our responsibilities to future generations, we will impose immense costs on our posterity.

To minimize sensitivity to climate change, African economies should be more diversified, and agricultural technology should optimize water usage through efficient irrigation and crop development. Considerable advances have been made in agricultural industries of southern Africa, particularly in South Africa and Zimbabwe.

As water resource stresses become acute in future water-deficit areas of Africa as a result of a combination of climate impacts and escalating human demand, there will be intensifying conflict between human and environmental demands on water resources. Because maintanance of healthy ecosystems is an underpinning to economic sustainability, there is need in each water basin management unit to identify and factor into development projects the need for environmental flows.

10.2.2. Food Security

10.2.2.1. Context of Food Security

Present and future prospects for food security are significant determinants of the impacts of climate change. International

***Table 10-2**: Indicators of regional vulnerability in Africa (WRI, 1996).*

(a) Vulnerability Indicators

	Expenditure on Food (% of consumption)	Food Aid (Cereals) kg per capita	Refugees	Adult Female Literacy (%)	Infant Mortality (per 1000)
African Region[a]					
– Northern	42	18	221,450	45	59
– Sudano-Sahelian	42	13	974,800	17	119
– Gulf of Guinea	39	6	819,750	28	109
– Central	39	3	480,500	41	91
– Eastern	37	4	1,408,150	43	102
– Indian Ocean	57	12	0	73	66
– Southern	57	15	1,793,800	53	85
Total	57	10	5,698,450	35	97
Comparison Country					
– Bangladesh	59	12	245,300	22	108
– Thailand	30	2	255,000	90	26
– Mexico	35	3	47,300	85	35
– Greece	30	-1	1,900	89	8
– United Kingdom	12	-3	24,600		7

(b) Regional Agriculture in Africa

	Pop. Density (pop. km^{-2})	Pop. Growth (%)	Crop Land (% of total)	Irri-gated Land (% of total)	Avg. Yield of Cereals (kg ha^{-1})	Ferti-lizer Use (kg yr^{-1})	Food Prod. Index (1970= 100)	GNP per Capita (US$)	GNP in Agri-culture (%)	GNP Growth Rate (% yr^{-1})	Public Agri-cultural Invest-ment (US$)
Region[a]											
Northern	226	2.25	5	27	1,973	94	115	1,285	17	3.60	25
Sudano-Sahelian	106	2.72	4	7	727	5	90	860	34	2.36	7
Gulf of Guinea	891	2.83	21	2	892	6	100	760	39	1.87	15
Central	145	2.70	4	1	923	2	87	760	22	2.15	5
Eastern	451	2.88	10	2	1,363	12	92	593	47	3.05	13
Indian Ocean	262	1.96	5	23	1,988	140	98	280	22	3.85	6
Southern	208	2.56	6	7	929	27	76	333	21	3.38	7
Total	253	2.65	6	8	1,098	25	92	355	30	2.75	11
Comparison Country											
Bangladesh	9,853	2.18	72	31	2,572	101	96	205	37	4.20	68
Thailand	1141	0.92	45	19	2,052	39	109	1,697	13	7.80	78
Mexico	491	1.55	13	21	2,430	69	100	2,971	8	1.50	129
Greece	795	0.07	30	31	3,700	172	101	6,530	17	1.60	25
UK	2,404	0.19	28	2	6,332	350	112	33,850	2	2.80	347

[a] **Northern**: Algeria, Egypt, Libya, Morocco, Tunisia; **Sudano-Sahelian**: Burkina Faso, Cape Verde, Chad, Djibouti, Eritria, The Gambia, Mali, Mauritania, Niger, Senegal, Somalia, Sudan; **Gulf of Guinea**: Benin, Cote d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone, Togo; **Central**: Angola, Cameroon, Central African Republic, Congo, Equatorial Guinea, Gabon, Sao Tome and Principe, Democratic Republic of Congo; **Eastern**: Burundi, Ethiopia, Kenya, Rwanda, Tanzania, Uganda; **Indian Ocean**: Comoros, Madagascar, Mautitius, Seychelles; **Southern**: Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe.

agricultural systems and socioeconomic conditions at the household level are major elements of vulnerability. The consequences of present vulnerability for hunger and nutrition are marked. Regional indicators related to food security are shown in Table 10-2.

Food production in most of SSA has not kept pace with the population increase over the past 3 decades. In Africa as a whole, food consumption exceeded domestic production by 50% in the drought-prone mid-1980s and more than 30% in the mid-1990s (WRI, 1998). Food aid constitutes a major proportion of net food trade in Africa, and in many countries it constitutes more than half of net imports. In Kenya and Tanzania, for instance, food aid constituted two-thirds of food imports during the 1990s. Despite food imports, per capita dietary energy supply (DES) remains relatively low (Hulme, 1996); about one-third of the countries in Africa had per capita DES of less than 2,000 kcal day^{-1} in the 1990s—lower than the minimum recommended intake (data from WRI, 1998).

Agricultural and economic growth must rise—perhaps by 4% yr^{-1}—to realize basic development goals. Today, only a few countries achieve this rate of growth. One consequence of agricultural growth could be a doubling by the year 2050 of cultivated land area—at great cost to the natural environment—unless there is greater investment in agricultural management and technology on existing cropland (Anon, 1999). The scale of food imports fosters dependence on food production in the rest of the world. Africa faces the risk that supplies will fluctuate drastically with the rise and fall of grain reserves and prices on international markets. A major challenge facing Africa is to increase agricultural production and achieve sustainable economic growth; both are essential to improving food security.

Agriculture is not only a vital source of food in Africa; it also is the prevailing way of life. An average of 70% of the population lives by farming, and 40% of all exports are earned from agricultural products (WRI, 1996). One-third of the national income in Africa is generated by agriculture. Crop production and livestock husbandry account for about half of household income. The poorest members of society are those who are most dependent on agriculture for jobs and income. On average, the poor from developing countries of SSA spend 60–80% of their total income on food (see Odingo, 1990; WRI, 1998; FAO, 1999b). Although industry is significant in a few patches, it still is in its infancy. In many countries, the level of mechanization—including irrigation, processing, and storage facilities—is particularly low.

High-quality land resources per household have shrunk in Africa over the past 2 decades, often dramatically. Traditional, social, and legal status in the sub-Saharan region is responsible for unequal access to land. This, in turn, increases the risk of resource degradation. Lack of land tenure security reduces the motivation to invest in conservation of resources.

Agriculture and household incomes are characterized by large interannual and seasonal variations. The annual flow of income normally rises and peaks during the harvest season. Nonagricultural and migrant, off-farm wage incomes are substitutes during the dry season. The period preceding the harvest is critical: Farmers engage in unemployment-induced migration to urban centers as one of the strategies for coping with scarcity. Fluctuations in annual food production resulting from climate variability place a heavy reliance on food aid, at the national and household levels.

Reduced food supplies and high prices immediately affect landless laborers who have little or no savings. Poverty, population, and sometimes conflicts combine to affect education in many African countries. As a result of population pressure as well as rural and urban economic depression, population mobility sets in. Populations move from the savanna to the forest, from plateaus to drained valleys, from landlocked countries to coastal

***Table 10-3**: Undernourishment in Africa (FAO, 1999b).*

Region	Number of People (millions) 1996–1997	% of Population 1979–1981	% of Population 1995–1997
Africa			
– Central Africa	35.6	36	48
– East and southern Africa	112.9	33.5	43
– West Africa	31.1	40	16
– North Africa	5.4	8	4
Other Regions			
– Caribbean	9.3	19	31
– Central America	5.6	20	17
– South America	33.3	14	10
– Eastern Asia	176.8	29	14
– South Asia	283.9	38	23
– Southeast Asia	63.7	27	13
– Western Asia	27.5	10	12
– Indian Ocean	1.1	31	24

***Table 10-4**: Comparison of indices of human development and food security for regions in developing countries [Human Development Index (UNDP, 1998); data from WRI (1998) and UNDP (1998)].*

Human Development Index (HDI)	**Food Security**			
	Low	Med-Low	Med-High	High
Low	West Africa, South Asia, East and South Africa, Central America, Central Africa			
Medium	South Pacific	Southeast Asia, North Africa		
High	East Asia, Caribbean	West Asia, South America, Central Asia	West Europe, Central and East Europe	Australasia, Indian Ocean, North America

areas and those with infrastructures, and from rural to urban centers within a country in search of better lands and opportunities (Davies, 1996). Internal mobility and its consequences vary from country to country: It is low in Ghana, Madagascar, Malawi, Burundi, and Rwanda but high in Burkina Faso and Kenya and very high in Cote d'Ivoire. Migrations lead to high and rising urban growth across the African region. This translates into increasing pressure on the environment, including social amenities.

The consequences of chronic and episodic food insecurity in Africa are evident in the prevalence of hunger. Nearly 200 million people in Africa are undernourished. In central, eastern, and southern Africa, more than 40% of the population is undernourished, and the number has risen over the past few decades. SSA is home to almost one-quarter of the developing world's food-deprived people, with variations across the continent (FAO, 1999b). Although west Africa has the largest total population of any of the African subregions, it has the fewest undernourished people. By contrast, east Africa has more than twice as many undernourished people. According to anthropometric surveys made between 1987 and 1998, 33% of African children are stunted, underweight, or wasted (FAO, 1999b) (see Table 10-3). Illiteracy and ignorance, along with poor housing and infrastructure, are predisposing conditions to ill health in many countries, which impacts food security.

African food security and potential to adapt to climate change can be portrayed by using national indicators. Of course, local conditions of vulnerability are critical; aggregate indicators are only one way of illustrating the relative risks and potential impacts of climate change. Two indices are shown in Table 10-4. The Human Development Index (HDI) is a composite of measures of life expectancy, literacy, education, and income (GDP per capita), as promoted by the United Nations Development Programme (UNDP). Except for north Africa, African regions score in the lowest group on the HDI. Among other world regions, only Central America is in the lowest group. A similar index of food security has been constructed, using indices of trends in food production, available food as a percentage of requirements, and arable land per capita (see Downing, 1991); north Africa is in the medium–low group. Relative to other regions, Africa clearly is among the regions with the lowest food security and the lowest ability to adapt to future changes (as indicated by the HDI).

The state of food security is not uniform, and there has been considerable progress in some countries (FAO, 1999b). For example, undernourishment in Ghana has decreased more rapidly than in any other country in the world, fueled by economic growth and consequent improvements in cropped area and yields. Plagued by population growth and conflict, Burundi is in stark contrast: Average daily food intake fell from 2,020 kcal in 1980 to 1,669 kcal in 1996.

The implications of this state of food insecurity in Africa for climate change are significant. The risks of adverse effects on agriculture, especially in semi-arid and subhumid regions and areas with more frequent and prolonged drought, become life-threatening risks. Internal coping mechanisms—through farm improvement, employment, and trade—are not likely to be adequate for many of the vulnerable populations. If food insecurity prevents private investment in agricultural economies (internal and from multinational corporations), resources for adapting to climate change may not keep pace with impacts. However, it also is clear that Africa has enormous resources—natural and human—that can be tapped to make rapid gains in food security and thus reduce the risk of adverse climate change.

10.2.2.2. Marine and Freshwater Fisheries

African nations possess a variety of lacustrine, riverine, and marine habitats with more than 800 freshwater and marine species (as noted in IPCC, 1998). GCMs do not provide direct information on water quality and other hydrological parameters that affect fisheries (Hlohowskyj *et al.*, 1996). As such, vulnerability assessments must translate projected atmospheric changes into changes in aquatic environments, making it possible for ecological and biological responses to climate change to be identified and evaluated. Most studies on the potential impacts of climate change on fisheries have been done for temperate-zone fisheries. In these studies, the emphasis has been to evaluate the impacts of changes in the availability of thermal habitat on fishery resources and evaluate the effects of temperature on physiological processes of fish.

Temperature increases may affect lake fisheries, although sensitivity across Africa is likely to vary. For example, Ntiba (1998) used empirically derived models to elucidate the relationship between long-term fishery yield data with climatic index value for Lakes Naivasha and Victoria in Kenya. The mean annual temperature is taken as the climatic index because of data availability and close correlation between air and water surface temperatures. The results indicate that in Lake Victoria, mean annual temperature has greater effect on fish yields than morphoedaphic index (MEI); the opposite is the case in Lake Naivasha. For Lake Naivasha, a rise of as much as 2°C above the current mean annual temperature may not even double the yield from the current 12 kg ha^{-1} yr^{-1} (yield regressed to temperature only). The additional effect of MEI will double and triple the yield with a rise of 1.5 and 2°C, respectively. For Lake Victoria, the maximum predicted yield under current climatic conditions is estimated to be 81.8 kg ha^{-1} yr^{-1} and is predicted to more than triple to 263.7 kg ha^{-1} yr^{-1} with a rise in temperature of 0.5°C. However, natural aquatic ecosystems have a finite carrying capacity at which fishery yields will reach a maximum sustainable yield (MSY) (Russell and Yonge, 1975); it is unlikely that the yield will exceed 84.2 kg ha^{-1} yr^{-1} in Lake Victoria, considering that the estimated MSY for the entire lake is 74.0 kg ha^{-1} yr^{-1} (Turner, 1996).

On Lake Kariba, Magadza (1996) found that drought years were accompanied by decreased fisheries catch. Hart and Rayner (1994) show that the distribution of copepods on the African continent is temperature-dependent, with species examined showing restricted temperature range preferences. In the laboratory, Magadza (1977) found that the optimum temperature for the reproduction of *Moinia dubia* is 24°C, with temperatures exceeding 28°C showing reproductive failure. Chifamba (2000) found negative relationships between catch per unit (CPU) effort and temperature in the pelargic *Limnothrissa miodon* fishery on Lake Kariba, whereas precipitation and river runoff were positively correlated with CPU. These observations indicate possible depression of planktivorous pelargic freshwater fisheries as a result of climate change impacts. Where such fisheries constitute a signifiant protein source, such impact will bear on food security.

Afurther consideration in the possible impacts of global warming on inland fisheries is the thermal behaviors of inland waters. In tropical areas, a unit change in temperature elicits a greater density change per unit temperature change. Thus, at the higher tropical temperatures indicated by climate models, thermal stratifications are likely to be more stable. In eutrophic lakes, anoxia and amonia intoxication leading to massive fish deaths—as repeatedly witnessed in Lake Chivero—are likely to be significant (Magadza, 1997; Moyo, 1997).

Aquaculture is a food production activity with one of the highest growth rates in the world. Risk management in aquaculture must take into account the level and frequencies of extreme events in assessing available technical options, based on the environment and climatic conditions.

Riverine fisheries will be affected. With a potential warming of 3–5°C projected for the next century, productivity of the Gambia River is estimated to increase by about 13–21% (Jallow *et al.,* 1999). There would be little or no effect on the suitability of the present habitat for some fish and shrimp species. In contrast, warming of more than 3°C will have negative impacts on habitats for catfish, and warming of more than 4°C will reduce the suitability of the present habitat for herring. Shrimp yield is estimated to increase by about 38–54%.

Upwelling of the Canary Current produced by the northeast and southwest tradewinds makes the fishery off the coast of Morocco one of the most productive in the world. Data from the Institut National de Recherche Haleutique du Maroc show that NAO weakens the upwelling, increases temperature, and reduces sardine stocks (Hilmi *et al*., 1998).

The pelagic fishing industry in the southwest of Africa (based on the Benguela upwelling) contains several migratory species, such as the anchovy (Crawford *et al.,* 1987). These species are an important resource in their own right, but they also are a key element in the food chain of larger fish, seals, and birds. Recruitment in these species is influenced by water temperature, and growth is affected by the state of the upwelling, both of which are linked to global climatic conditions (Shannon *et al*., 1990; Siegfried *et al.*, 1990). For instance, there is a phenomenon similar to the El Niño effect on the fisheries of Peru that leads to an intrusion of warm, nutrient-poor water from the north in some years, which severely depresses fish yields (Shannon *et al*., 1990). The net impact of global climate change on southern African fisheries remains unclear because the potential impact on ocean circulation and wind shear in the coastal zone is uncertain. In the event of major reorganization of the circulation of the southern oceans (Hirst, 1999)—which is a possibility at high rates of warming—the impacts most likely would be severe.

10.2.2.3. Crop Production

Major impacts on food production will come from changes in temperature, moisture levels, ultraviolet (UV) radiation, CO_2 levels, and pests and diseases. CO_2 enrichment increases photosynthetic rates and water-use efficiency (WUE) (see Chapter 5). The direct effects are largest on crops with C_3 photosynthetic pathway (wheat, rice, and soybean) compared with C_4 crops (maize, sorghum, millet, and sugarcane). Increases in local temperatures may cause expansion of production into higher elevations. The grain filling period may be reduced as higher temperatures accelerate development, but high temperatures may have detrimental effects on sensitive development stages such as flowering, thereby reducing grain yield and quality. Crop water balances may be affected through changes in precipitation and other climatic elements, increased evapotranspiration, and increased WUE resulting from elevated CO_2.

Specific examples of impacts on crops are available. Pimentel (1993) notes that global warming is likely to alter production of rice, wheat, corn, beans, and potatoes—staples for millions of people and major food crops in Africa. Staple crops such as wheat and corn that are associated with subtropical latitudes may suffer a drop in yield as a result of increased temperature, and rice may disappear because of higher temperatures in the tropics (Odingo, 1990).

The possible impact of climate change on maize production in Zimbabwe was evaluated by simulating crop production under climate change scenarios generated by GCMs (Muchena and Iglesias, 1995). Temperature increases of 2 or 4°C reduced maize yields at all sites; yields also decreased under GCM climate change scenarios, even when the beneficial effects of CO_2 were included. It is suggested that major changes in farming systems can compensate for some yield decreases under climate change, but additional fertilizer, seed supplies, and irrigation will involve an extra cost. The semi-extensive farming zone was particularly sensitive to simulated changes in climate, and farmers in this zone would be further marginalized if risk increases as projected.

Analysis of potential impacts, using dynamic simulation and geographic databases, has been demonstrated for South Africa and the southern Africa region by Schulze *et al*. (1993) (see also Schulze *et al.*, 1995; Hulme, 1996; Schulze, 2000). Relatively homogenous climate and soil zones were used to run agrohydrological, primary productivity, and crop yield models. The results reaffirm the dependence of production and crop yield on intraseasonal and interannual variation of rainfall.

Impacts on crops need to be integrated with potential changes in the agricultural economy. Yates and Strzepek (1998) describe an integrated analysis for Egypt (see Figure 10-8). Their model is linked to a dynamic global food trade model, which is used to update the Egyptian sector model and includes socioeconomic trends and world market prices of agricultural goods. Impacts of climatic change on water resources, crop yields, and land resources are used as inputs into the economic model. The climate change scenarios generally had minor impacts on aggregated economic welfare (sum of consumer and producer surplus); the largest reduction was approximately 6%. In some climate change scenarios, economic welfare slightly improved or remained unchanged. Despite increased water availability and only moderate yield declines, several climate change scenarios showed producers being negatively affected by climate change. The analysis supports the hypothesis that smaller food-importing countries are at risk of adverse climate change, and impacts could have as much to do with changes in

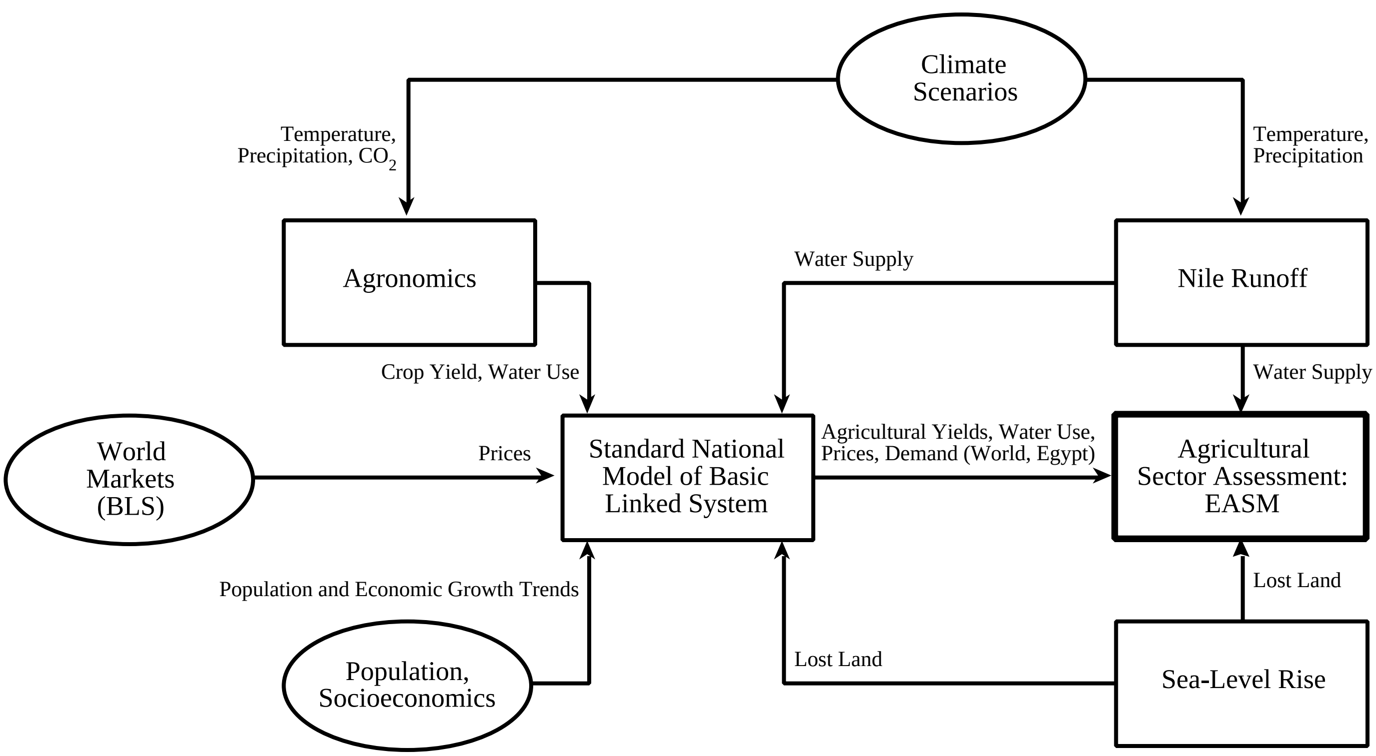

Figure 10-8: Schematic of forward-linkage approach to integrated assessment of climate change impacts on Egypt, using agricultural sector model (Yates and Strzepek, 1998).

world markets as with changes in local and regional biophysical systems and shifts in the national agricultural economy.

10.2.2.4. Livestock

Other than pigs, domestic livestock in Africa are concentrated in the arid and semi-arid zones. This is because the more humid areas were historically prone to livestock diseases such as *nagana* (a trypanosome carried by the tsetse fly—Ford and Katondo, 1977), typically support grasses of low digestibility (Scholes, 1990, 1993), and often are densely settled by crop agriculturalists. The overwhelming majority of these animals feed predominantly off natural grasslands and savannas, although crop residues are an important supplement during the dry season. Many urban and rural families also keep poultry.

Domestic livestock play a central role in many African cultures. Cattle and camels, in particular, have an importance that goes beyond the production of meat. Their value is based on the full set of services they supply (milk, meat, blood, hides, draft power), their asset value as a form of savings, and their cultural symbolism. It would be difficult and damaging for these cultures to abandon pastoralism in the event that it becomes climatically, environmentally, or economically unviable.

Although classical concepts of animal carrying capacity may not be very useful as local management tools in the context of African semi-arid systems with high interannual variability (Behnke *et al.*, 1993), they remain valid as indicators of animal production when they are applied over decadal periods and large areas. Many researchers have demonstrated a strong link between long-term, large-area herbivore biomass (LHB, kg km^{-2}) in African wildlife and pastoral systems and mean annual precipitation (MAP, mm) (Coe *et al.*, 1976; van den Berg, 1983). Subsequent studies have shown that this relationship is strongly influenced by soil type or its proxy, the underlying geology (East, 1984; Fritz and Duncan, 1993). These relationships have the form log(LHB) = A x log(MAP) + B, where A and B are constants for a particular soil type. Because the values of A lie between 1.45 and 1.55, the relationships are exponentially increasing but approximately linear over the typical range of interannual variation at one site (see also Le Houerou, 1998, for a similar analysis in west Africa and the Mediterranean basin). Thus, in broad terms, changes in range-fed livestock numbers in any African region will be directly proportional to changes in annual precipitation. Given that several GCMs predict a decrease in MAPon the order of 10–20% in the main semi-arid zones of Africa, there is a real possibility that climate change will have a negative impact on pastoral livelihoods. The following additional factors must be considered.

The causal chain between rainfall and animal numbers passes through grass production, which also is approximately linearly related to rainfall (Breman, 1975; Le Houerou and Hoste, 1977; Rutherford, 1995). The slope of this relationship, which can be expressed as WUE, is a function of soil nutrient availability (De Ridder *et al.*, 1982; Scholes, 1993). WUE also is a function of CO_2 concentration in the atmosphere (Mooney *et al.*, 1999), especially in semi-arid regions. Because the CO_2 concentration will rise in the future, its positive impact on WUE (which is on the order of 20–30% for doubled CO_2, even in C_4-dominated grasslands such as these) will help to offset reduction in rainfall of the same magnitude. Simulations of grassland production in southern Africa indicate an almost exact balancing of these two effects for that region (Scholes *et al*., 2000).

About 80% of the grazing lands of Africa are in savannas, a vegetation formation that consists of a mix of trees and grasses. Grass production in savannas is strongly depressed by tree cover (see the many references reviewed by Scholes and Archer, 1997). Because domestic livestock, with the exception of goats, predominantly eat the grass in these systems, future changes in tree cover are an important issue from the point of view of carbon sequestration and livestock production. Tree biomass ultimately is related to climate and soil type, but the mechanism appears to be via fire frequency and intensity. If fire frequency and intensity were to decrease—as a result of climate changes (for instance, an increase in dry-season rainfall) or, more likely, changes in land management—woody cover would increase. This has been demonstrated in numerous fire experiments in Africa (Trapnell *et al.*, 1976; Booysen and Tainton, 1984). Given the vast area of the savannas, the carbon sequestration potential is substantial (Scholes and van der Merwe, 1996). In addition, emissions of tropospheric ozone (O_3) precursors would decrease if savanna burning were reduced. The disadvantage would be a more than proportional decrease in livestock carrying capacity, as a result of the nonlinear suppressive effect of trees on grass production.

The bioclimatic limit of savannas in southern Africa is related to winter temperatures. An increase in temperature of 1–2°C—well within the range predicted for next century—would make the montane grasslands (highveld) of southern Africa susceptible to invasion by savanna trees (Ellery *et al*., 1990).

In moister regions, animal productivity is limited not by the gross availability of fodder but by its protein (nitrogen) content (Ellery *et al.*, 1996). Increasing the CO_2 concentration or the rainfall will not increase the protein availability; thus, livestock in these regions are likely to be less responsive to the direct effects of atmospheric and climate change. Under elevated CO_2, the carbon-to-nitrogen ratio of forage will decrease, but this will not necessarily lead to decreased forage palatability despite the dilution of protein (Mooney *et al*., 1999). This may be because in grasses, the bulk of the excess carbon is stored in the form of starch, which is readily digestible. Widespread use of protein and micronutrient feed supplements and new technology for the control of veterinary diseases will have a greater impact on livestock numbers and productivity, especially in the “miombo” region of south central Africa.

Domestic livestock, like other animals, have a climate envelope in which they perform optimally. The limits of the envelope are quite broad and can be extended by selecting for heat or cold tolerance, feed supplementation, or providing physical shelter for the animals. African cattle are mostly from the *Bos indicus* line, which is more heat-tolerant than the European line of *Bos taurus*. In extremely hot areas (mean daily warm-season temperatures greater than body temperature), even the *Bos indicus* breeds are beyond their thermal optimum (Robertshaw and Finch, 1976). Meat and milk production declines, largely because the animals remain in the shade instead of foraging. There is limited potential for extending this limit through breeding. Adaptation would require substitution by a species such as the oryx, which is physiologically equipped for high temperatures and low water supply.

In the higher altitude and higher latitude regions of Africa, livestock (typically sheep) currently are exposed to winter temperatures below their optimum. Mortality often results when cold periods coincide with wet periods, if the animals have not been herded to shelter. These episodes are likely to decrease in frequency and extent in the future.

Livestock distribution and productivity could be indirectly influenced via changes in the distribution of vector-borne livestock diseases, such as *nagana* (trypanosomiasis) and the tick-borne East Coast Fever and Corridor Disease (Hulme, 1996). Simulations of changes in the distribution of tsetse fly (*Glossina spp*.) indicate that with warming it could extend its range southward in Zimbabwe and Mozambique, westward in Angola, and northeast in Tanzania, although in all these simulations there were substantial reductions in the prevalence of tsetse in some current areas of distribution. The tick *Riphicephalus appendiculatus* was predicted to decrease its range in southern and eastern Africa and increase its range in the central and western part of southern Africa (Hulme, 1996).

One land-use model (IMAGE 2.0—Alcamo, 1994) projects that large parts of Africa will be transformed to pastoral systems during the 21st century. The model logic that leads to this conclusion is that increasing urbanization and a rising standard of living typically are associated with a change in dietary preference toward meat. The area that currently is used for meat production therefore would need to expand, assuming that meat demand was not met by import or by increased productivity of existing herds. These are reasonable but untested assumptions, and their consequences have major implications for biodiversity conservation and atmospheric composition. The areas indicated as being converted to pastures (largely the subhumid tropics) already support cattle to some degree. Increased cattle production would require widespread tree clearing (leading to conversion of a carbon sink into a carbon source), eradication of key cattle diseases, and the use of protein and micronutrient feed supplements. The quantity of fuel consumed by savanna fires would decrease (because it would be grazed), reducing the release of pyrogenic methane (CH_4) and O_3 precursors, but the production of methane from enteric fermentation would increase. Because methane production per unit of grass consumed is higher for enteric fermentation than for savanna fires (Scholes *et al.*, 1996), the result is likely to be a net increase in radiative forcing.

10.2.2.5. Impacts of Drought and Floods

Food security in Africa already is affected by extreme events, particularly droughts and floods (e.g., Kadomura, 1994; Scoones *et al.,* 1996). The ENSO floods in 1998 in east Africa resulted in human suffering and deaths, as well as extensive damage to infrastructure and crops in Kenya (Magadza, 2000). Floods in Mozambique in 2000 and in Kenya in 1997–1998 sparked major emergency relief as hundreds of people lost their lives and thousands were displaced from their homes (Brickett *et al.*, 1999; Ngecu and Mathu, 1999; see also <www.reliefweb.int>). The cost in Kenya alone was estimated at US$1 billion (Ngecu and Mathu, 1999). Droughts in 1991–1992 and 1997–1998 affected livelihoods and economies and heightened renewed interest in the impacts of climatic hazards (e.g., Kadomura, 1994; Campbell, 1999). For example, the impacts of the 1991–1992 drought in Zimbabwe are estimated to have been 9% of GDP (Benson and Clay, 1998).

Such climatic episodes can serve as an analog of climate change. Irrespective of whether climate change will cause more frequent or more intense extreme events, it is apparent that many aspects of African economies are still sensitive to climatic hazards. At the local level, some coping strategies are less reliable (Jallow, 1995)—for instance, Campbell (1999) notes that plants and trees used as food by pastoralists in southern Kenya declined between 1986 and 1996. National governments often struggle to provide food security during times of crisis (Ayalew, 1997; Gundry *et al.,* 1999). For national and international agencies, the cost of climatic hazards—impacts, recovery, and rehabilitation—may result in a shift in expenditure from reducing vulnerability to simply coping with immediate threats (e.g., Dilley and Heyman, 1995).

10.2.2.6. Adaptation Strategies

The nature and processes of human adaptation to long-range climate change are poorly understood, especially in Africa (but see Chemane *et al.*, 1997; Vogel, 1998). Often, human responses are assumed, or assumed to be rational with foresight and equity. Chapter 18, Smith and Lenhart (1996), and Smithers and Smit (1997) provide overviews; national assessments provide more detail.

A promising approach for much of Africa is to cope with current climate variability through the use of seasonal climate forecasting (e.g., Mason *et al*., 1996; Mattes and Mason, 1998; Washington *et al*., 1999; Dilley, 2000). If farmers can adapt to current year-to-year variability through the use of advance information on the future season's climate and institutional systems are in place to respond to short-term changes (such as early warning systems), communities will be in a position to adapt to longer term climate changes. For example, a seasonal maize water-stress forecast for the primary maize-growing regions of South Africa and Zimbabwe anticipates water stress 6 months prior to harvest, with hindcast correlation over 16 seasons of 0.92 for South Africa and 0.62 for Zimbabwe, based on correlations between water stress and historical global SST and sea-level pressure records (Martin *et al*., 2000). Similar forecasts are possible in other regions and for other crops; however, seasonal forecasting by itself will not improve food security (e.g., Stack, 1998).

Better soil and water conservation practices, more tolerant crop varieties, improved pest and weed control, and more use of irrigation also are needed to adapt to changes in the weather. Omenda *et al*. (1998) recommend that in areas predicted to have a decline in precipitation, research into the development of maize varieties that are higher yielding, drought-resistant, early maturing, and disease- and pest-tolerant is desirable. They further suggest that methods of improving maize culture be studied, including use of inorganic fertilizers and manure and changes in planting dates. Better adaptation to climate change also will result from the use of improved technologies in agriculture—for example, in irrigation and crop husbandry. It has been suggested (Pinstrum-Anderson and Pandya-Lorch, 1999), for example, that by failing to capitalize on new opportunities that biotechnology offers, SSAmay further add to its food insecurity and poverty problems.

Increased meat production can be achieved without massive expansion of area grazed or size of the herds, by application of modern herd and animal diet management. In many situations, this would require a cultural shift from regarding livestock principally as an asset and symbol to regarding them as a production system. Cow-calf systems with supplemental feeding can achieve offtakes of 40% yr^{-1} (compared to the 10–20% typical of most current herd management in Africa), permitting lower livestock numbers per hectare (Preston and Leng, 1987). This would achieve a reduction in CO_2 and CH_4 emissions. A limited amount of increased heat tolerance can be introduced through breeding programs.

The Senegal River basin (SRB) provides an illustration of sensitivity to climatic variations and opportunities for adaptation. The SRB is undergoing fundamental environmental, hydrologic, and socioeconomic transitions (Venema *et al*., 1997). Senegal, Mauritania, and Mali—through the river basin development authority, the Organisation pour la Mise en Valeur du Fleuve Senegal (OMVS)—are promoting irrigated rice production for domestic consumption in the river basin to ease the severe foreign exchange shortfalls facing these riparian nations. With the recent completion of Manantali and Diama dams, year-round irrigated agriculture is now possible in the SRB. The full agricultural development potential of the SRB is constrained, however, by the basin's limited water resources, which are sensitive to climatic variations. An alternative approach to the SRB's scarce water resources is an agricultural development policy that is based on village-scale irrigation projects and intensive, irrigated agroforestry projects (Venema *et al.*, 1997). Village-scale irrigation is dedicated to low-water-consumption cereal grain crops and is managed by traditional sociopolitical structures. The proposed agroforestry production system has the dual objectives of using irrigation to reestablish a protective biomass cover in the desertifying river valley and reversing drought-induced migration from rural to urban areas. A comparative river system simulation was carried out to analyze the effects of the rice production development policy and the natural resources management policy on the SRB's full agricultural development potential. The simulation study compared three alternative hydrologic scenarios, using the pre-drought era, the 1970s-level drought, and the 1980s-level drought. Dynamic programming applied to water allocation in the Manantali reservoir showed that lower overall water demands for the natural resource policy scenarios had higher agricultural development potential than the proposed policy based on rice production.

Asignificant drawback in combating effects of climate variability is the failure of African governments to devolve power to people who are affected and to link environmental degradation to economic policy (Darkoh, 1998). Consequently, many programs lack local support or are undermined by conflicting trade and agricultural policies pursued by governments. It is contended that, for sustainable development strategies to work, policies should put the welfare of people at the center of the development agenda and give them the rights and power to determine their future. Policies should empower the people to develop adaptive strategies toward sustainable livelihoods. Moreover, threats posed to the environment and development by protection and overconsumption in the north and structural adjustment programs (SAPs) call for the removal of distortions created by the import barriers of developed countries, curbing of overconsumption, and a fundamental revision in the structure of SAPs to help alleviate poverty and protect the environment in these African countries. It is in the interest of the global community that the environment in Africa is protected.

Operational early warning systems in Africa—including the SADC Regional Early Warning Unit, the U.S. Agency for International Development (USAID) Famine Early Warning System Network, and the World Food Program (WFP) Vulnerability Assessment and Mapping unit—assess the vulnerability of rural households in many parts of Africa to food insecurity each year. Vulnerability assessments generally develop a picture of which geographic areas and which social groups will be unlikely to meet their subsistence needs before the next agricultural season, based on a convergence of available environmental and socioeconomic information (USAID, 1999). The USAID Sahel vulnerability assessment for 1999–2000 estimated that 3.8 million people were moderately food insecure in a high-rainfall year (USAID, 2000). This could signify chronic vulnerability resulting from structural weaknesses caused by desertification, climate change, and other long-term environmental and socioeconomic phenomena.

10.2.3. Natural Resource Management and Biodiversity

10.2.3.1. Forest and Woodland Resources

In Africa, forests—as defined and reported by FAO (1999a)—cover 5 million km^2, one-sixth of the continent's land area. The moist tropical forests of the Congo constitute the second most extensive rainforest in the world and a globally important reserve of carbon. Trees and shrubs constitute an important component of the more than 12 million km^2 of agricultural lands, pastures, shrublands, and savannas outside of closed-canopy forest areas.

Trees and shrubs provide ecosystem services of carbon sequestration, storing and transpiring water required for precipitation, maintaining soil fertility, and forming habitats for a diverse array of plant and animal species. Moreover, forest and woodland species also provide firewood, structural timber, traditional medicines, staple foods, and drought emergency foods. Because a large fraction of the population lives in rural areas, they depend on trees and shrubs for many of their subsistence needs. Indeed, firewood and charcoal provide approximately 70% of the energy used in Africa. Moreover, the export of timber, nuts, fruit, gum, and other forest products generates 6% of the economic product of African countries (FAO, 1999a). Thus, climate change renders vulnerable the large part of the African population that is dependent on forest species for subsistence needs and the nontrivial fraction of the economy that is based on forest products.

Because climate change alters the spatial and temporal patterns of temperature and precipitation, the two most fundamental factors determining the distribution and productivity of vegetation—geographical shifts in the ranges of individual species and changes in productivity—constitute the most likely impacts of CO_2-induced climate change on forest species. Research in Senegal (Gonzalez, 1997, 2001) has documented retraction of mesic species to areas of higher rainfall and lower temperature as a result of desertification in the last half of the 20th century. These changes have caused a 25–30 km southwest shift of Sahel, Sudan, and Guinean vegetation zones in half a century, proceeding at an average rate of 500–600 m yr^{-1}—foreshadowing the magnitude of projected vegetation shifts driven by CO_2-induced climate change (Davis and Zabinski, 1992). In northwest Senegal, the human population density is 45 people km^{-2}, whereas forest species can support only 13 people km^{-2} under altered conditions (Gonzalez, 1997).

Dry woodlands and savannas in semi-arid and subhumid areas will be increasingly subjected to drying in the next century, as well as increasing land-use intensity—including conversion to agriculture (Desanker *et al.*, 1997). Moreover, CO_2-induced climate change is very likely to alter the frequency, intensity, seasonality, and extent of vegetation fires that are critical to the maintenance of areas such as the Serengeti grasslands of east Africa, the miombo woodlands of southern Africa, and the fynbos of the Cape. Across the continent, farmers traditionally use fire to clear agricultural fields in forest areas and areas outside closed-canopy forest; pastoralists and hunter-gatherers use fire to improve the quality of plant resources available during the dry season. Satellite remote sensing reveals that more than half of the continent experiences a fire regime with a frequency greater than once per decade (Kendall *et al.*, 1997; Levine *et al.*, 1999).

Although the broad geographical pattern of fire-prone vegetation clearly is climatically related (van Wilgen and Scholes, 1997), the aspect of the fire regime that is most sensitive to the type and degree of climate change suggested for Africa is likely to be fire intensity, rather than its frequency or extent. Fire intensity is related largely to the available dry-season fuel load, which in turn is strongly and positively related to rainfall in the preceding wet season and nonlinearly related to woody plant cover. In the miombo woodlands, it is predicted that increased fire will expand savanna areas at the expense of wooded areas (Desanker *et al.*, 1997). Because emissions of CH_4, tropospheric O_3 precursors, and aerosols from vegetation fires in Africa constitute a significant contribution to the global budgets of these species (Crutzen and Andreae, 1990; Hao *et al.*, 1990; Scholes *et al.*, 1996), changes in the African fire regime could have consequences for global and regional climate.

Modeling of the distribution of forest species on the basis of the Holdridge (1967) life zone classification has projected changes from mesic vegetation to xeric vegetation in Tanzania and The Gambia (Jallow and Danso, 1997) but a shift from arid vegetation to moist vegetation in Mozambique (Bila, 1999). It is not suggested that vegetation formations and their associated fauna (biomes) will migrate as a unit. It is more likely that species will respond to changing climate and disturbance regimes individualistically, with substantial time lags and periods of reorganization. The broad pattern of productive potential of vegetation zones is likely to move with greater spatial integrity because there is a degree of functional redundancy in ecosystems.

The most promising adaptation strategies to declining tree resources include natural regeneration of local species, energy-efficient cookstoves, sustainable forest management, and community-based natural resource management. The most effective adaptation to the decline of trees and shrubs in semi-arid areas is natural regeneration of local species. In addition, the *ban ak suuk* cookstove in Senegal and the *jiko* ceramic stove in Kenya have both produced energy-efficient gains in semi-arid areas (Dutt and Ravindranath, 1993). These practices generally depend on the ability of local people to exercise power to inventory and manage local resources in systems of community-based natural resource management. Decentralization of decisionmaking and revenue allocation authority has promoted efficient forest management in small areas of Niger, Madagascar, and Zimbabwe (FAO, 1999a). All of these practices constitute "no regrets" strategies that society would want to undertake under any climate scenario for their intrinsic environmental and economic benefits.

10.2.3.2. Indigenous Biodiversity and Protected Areas

Africa occupies about one-fifth of the global land surface and contains about one-fifth of all known species of plants, mammals, and birds in the world, as well as one-sixth of amphibians and reptiles (Siegfried, 1989). This biodiversity is concentrated in several centers of endemism. The Cape Floral Kingdom (fynbos), which occupies only 37,000 km^2 at the southern tip of Africa, has 7,300 plant species—of which 68% occur nowhere else in the world (Gibbs, 1987). The adjacent Succulent Karoo biome contains an additional 4,000 species, of which 2,500 are endemic (Cowling *et al.,* 1998). These floristic biodiversity hotspots both occur in winter rainfall regions at the southern tip of the continent and are threatened particularly by a shift in rainfall seasonality (for instance, a reduction in winter rainfall amounts or an increase in summer rainfall, which would alter the fire regime that is critical to regeneration in the fynbos). Other major centers of plant endemism are Madagascar, the mountains of Cameroon, and the island-like Afromontane habitats that stretch from Ethiopia to South Africa at altitudes above about 2,000 m (Mace *et al.,* 1998). Montane centers of biodiversity are particularly threatened by increases in temperature because many represent isolated populations with no possibility of vertical or horizontal migration. Several thousand species of plants alone are potentially affected.

The broad patterns of African zoogeography also are climatically linked, but the location of concentrations of biodiversity and endemism, at least in the higher animals, is located in the savannas and tropical forests. World antelope and gazelle biodiversity (more than 90% of the global total of 80 species) is concentrated in Africa (Macdonald, 1987). Changes in climate of the magnitude predicted for the 21st century could alter the distribution range of antelope species (Hulme, 1996).

This biodiversity forms an important resource for African people. Uses are consumptive (food, fiber, fuel, shelter, medicinal, wildlife trade) and nonconsumptive (ecosystem services and the economically important tourism industry).

For a sample of 39 African countries, a median 4% of the continental land surface is in formally declared conservation areas in southern Africa (MacKinnon and MacKinnon, 1986). The fraction of landscape that is conserved varies greatly between countries (from 17% in Botswana to 0% in four countries), as does the degree of actual protection offered within nominally conserved areas (MacKinnon and MacKinnon, 1986). A very large fraction of African biodiversity occurs principally outside of formally conserved areas (especially in central and northern Africa), as a result of a relatively low rate of intensive agricultural transformation on the continent. This will no longer be true if massive extensification of agriculture and clearing of tropical forests occurs in the humid and subhumid zones, as is predicted to occur in the next century by some land-cover change models (Alcamo, 1994). Patterns of human pressure, including grazing by domestic stock, also will be altered and intensified by climate change. Land-use conversion effects on biodiversity in affected areas will overshadow climate change effects for some time to come.

In the medium term (~10–20 years), biodiversity of indigenous plants and animals in Africa is likely to be affected by all of the major environmental changes that constitute climate change. These include changes in ambient air temperature, rainfall and air vapor pressure deficit (which combine to cause altered water balance), rainfall variability, and atmospheric CO_2.

Africa—like the other continents, though perhaps to a greater degree—is characterized by ecosystem control through disturbance, such as fire (Bond and van Wilgen, 1996) and grazing regimes. Changing disturbance regimes will interact with climate change in important ways to control biodiversity—for instance through rapid, discontinous ecosystem “switches.” For example, changes in the grazing and fire regime during the past century are thought to have increased woody-plant density over large parts of southern Africa. Ecosystem switches are accompanied by drastic species shifts and even species extinction. Subtle changes in species composition of rich ecosystems such as forests will impact biodiversity resources. A significant reduction in rainfall or increase in evapotranspiration in Angola would threaten the Okavango delta wetland in Botswana. Much larger scale ecosystem switches (e.g., savanna to grassland, forest to savanna, shrubland to grassland) clearly occurred in the past (e.g., during the climatic amelioration dating from the last glacial maximum), but diversity losses were ameliorated by species and ecosystem geographical shifts. The geographical range shifts recquired to preserve biodiversity into the future will be strongly constrained by habitat fragmentation and cannot realistically be accommodated by a static nature reserve network with the low areal coverage evident in Africa.

Theory required to predict the extent and nature of future ecosystem switches and species geographical shifts in Africa is lacking, and case studies are few. The response of major vegetation types to changes such as rising atmospheric CO_2 are almost unstudied, although early evidence (Midgley *et al.,* 1999; Wand *et al.,* 1999) suggests, for example, that these responses may increase WUE in grass species significantly, which may increase grass fuel load or even increase water supply to deeper rooted trees. Recent analysis of tree/grass interactions in savannas suggests that rising atmospheric CO_2 may increase tree densities (Midgley *et al.,* 1999); this kind of ecosystem switch would have major implications for grazing and browsing animal guilds and their predators. For southern Africa, between one-quarter and one-third of current reserves were predicted to experience a biome shift (a major change in the dominant plant functional types) under the equilibrium climate resulting from a twice-preindustrial CO_2 concentration (Hulme, 1996). In South Africa, increased aridity in the interior Bushmanland plateau will introduce a desert-like environment to the country (Rutherford *et al.,* 1999). Analysis for South African conservation areas (Rutherford *et al.,* 1999) shows potentially large losses of plant species diversity in this semi-arid region with low landscape heterogeneity.

Thus, the vegetation and animal communities that many reserves aim to conserve will no longer be within their preferred bioclimatic region. Migration of animals to conserved areas with more suitable climate (if these exist) will be constrained by fragmentation of intervening ecosystems and potentially hostile landscapes. The required rate of migration may be too rapid for unassisted movement of most plant species, especially over relatively flat landscapes (Rutherford *et al.,* 1995). Without adaptive and mitigating strategies, the impact of climate change will be to reduce the effectiveness of the reserve network significantly, by altering ecosystem characteristics within it and causing species emigrations or extinctions.

At particular risk of major biodiversity loss are reserves on flat and extensive landscapes, those in areas where rainfall regime may change seasonality (e.g., the southern Cape), those where the tree/grass balance is sensitive to CO_2 conditions, and those where the fire regime may be altered. Species most at risk are those with limited distribution ranges and/or poor dispersal abilities, habitat specialists (soil specialists in the case of plants), and those that are responsive to specific disturbance regimes.

Mitigation and adaptation strategies will be greatly strengthened by a risk-sharing approach between countries, which could attempt to share the burden of conserving critical populations in a collaborative way. Part of this risk-sharing approach could include transboundary nature reserves, where this is appropriate for increasing connectivity in areas projected to change significantly. The corridor approach within and between countries would have the added benefit of increasing reserve resilience to current climate variability and would increase attractiveness to the tourism industry. Economic incentives, however, may differ across geographic scales. For the moist tropical forests of Masoala National Park in northeast Madagascar, economic incentives favor conservation at local and global scales, although logging provides more profit at a national scale (Kremen *et al.*, 2000).

A high degree of uncertainty is associated with predictions of the biodiversity effects of climate change. No systematic analysis of mechanisms of ecosystem switches, or areas exposed to them, has been carried out. Although fire and atmospheric CO_2 seem to be important determinants of ecosystem structure and function, little research is available to predict how these factors will interact with other environmental changes. The effects of CO_2 on grass water use may be an important mitigator of negative effects on productivity for grazer guilds in much of subtropical Africa. Effects of shifts of disease-prone areas on animal populations are unstudied.

10.2.3.3. Migratory Species

10.2.3.3.1. Large-mammal migratory systems

The vast herds of migratory ungulates in east and southern Africa remain a distinguishing ecological characteristic of the continent. A major migratory system is located in the Serengeti area of Tanzania and the Masai-Mara region of Kenya. Reduced large-mammal migratory systems persist in the Kalahari (Botswana, South Africa, and Namibia) and Etosha (Namibia) areas of southern Africa.

Migrations typically are regular, and between dry-season and wet-season grazing areas, and to that extent they are sensitive to climate change. There is currently no indication that the broad pattern of seasonality is likely to change in the Serengeti or the Kalahari, since they are controlled by gross features of the atmospheric circulation (the monsoon system and the position of the Hadley cells). The intensity of seasonality, and the absolute annual rainfall total could change, by about 15% in either direction (Hulme, 1996). This is well within the range of interannual variability. Thus the migratory systems are likely to persist if land-use pressures permit them to.

10.2.3.3.2. Bird migrations

About one-fifth of southern African bird species migrate on a seasonal basis within Africa, and a further one-tenth migrate annually between Africa and the rest of the world (Hockey, 2000). A similar proportion can be assumed for Africa as a whole. One of the main intra-Africa migratory patterns involves waterfowl, which spend the austral summer in southern Africa and winter in central Africa. Palearctic migrants spend the austral summer in locations such as Langebaan lagoon, near Cape Town, and the boreal summer in the wetlands of Siberia. If climatic conditions or very specific habitat conditions at either terminus of these migratory routes change beyond the tolerance of the species involved, significant losses of biodiversity could result. Although the species involved have some capacity to alter their destinations, in an increasingly intensively used world the probability of finding sufficient areas of suitable habitat in the new areas is small. The current system of protected habitats under the Ramsar Convention is based on the present distribution of climate.

10.2.3.3.3. Locust migrations

Aperiodic locust outbreaks characterize the desert/semi-arid fringe in southern Africa and the Sahelian region. The population biology of the outbreak phenomenon is strongly linked to climate, particularly the pattern of soil moisture and temperature (Hanrahan *et al.*, 1992). Outbreaks typically occur when a dry period is followed by good rains—for instance, in southern Africa following an El Niño episode. Changes in El Niño frequency would impact the timing, location, and extent of locust outbreaks in ways that presently are unpredictable.

10.2.3.3.4. Human migratory systems

Semi-arid areas of the Sahel, the Kalahari, and the Karoo historically have supported nomadic societies that respond to intra-annual rainfall seasonality and large interannual variability through migration. Nomadic pastoral systems are intrinsically quite robust to fluctuating and extreme climates (because that is what they evolved to cope with), provided they have sufficient scope for movement and other necessary elements in the system remain in place. The prolonged drying trend in the Sahel since the 1970s has demonstrated the vulnerability of such groups to climate change when they cannot simply move their axis of migration because the wetter end already is densely occupied and permanent water points fail at the drier end. The result has been widespread loss of human life and livestock and substantial changes to the social system.

10.2.4. Human Health

The IPCC *Special Report on Regional Impacts of Climate Change* (IPCC, 1998) acknowledges that climate will have an impact on vector-borne diseases. The assessment in that report is limited to a qualitative analysis of the impacts. The report identifies the scarcity of disease distribution maps and models as a handicap to establishing current baseline limits. In the case of malaria, however, a continental effort—Mapping Malaria Risk in Africa—is underway. No such parallel efforts, however, are underway for other diseases in the African continent that may be affected by climate change (e.g., arboviruses, trypanosomiasis, schistosomiasis). No specific references are made to water- and food-borne and epizootic/epidemic diseases in Africa.

In recent years it has become clear that climate change will have direct and indirect impacts on diseases that are endemic in Africa. Following the 1997–1998 El Niño event, malaria, Rift Valley fever, and cholera outbreaks were recorded in many countries in east Africa (see Table 10-5 for a summary of disease outbreaks for the 1997–1999 period). The meningitis belt in the drier parts of west and central Africa is expanding to the eastern region of the continent. These factors are superimposed upon existing weak infrastructure, land-use change, and drug resistance by pathogens such as *Plasmodium falciparum* and *Vibrio cholerae.*

10.2.4.1. Vector-Borne Diseases: Malaria

Although the principal causes of malaria epidemics in the African highlands still are a subject of debate in the literature (Mouchet *et al*., 1998), there is increasing evidence that climate change has a significant role (WHO, 1998). In a highland area of Rwanda, for example, malaria incidence increased by 337% in 1987, and 80% of this variation could be explained by rainfall and temperature (Loevinsohn, 1994). A similar association has been reported in Zimbabwe (Freeman and Bradley, 1996). Other epidemics in east Africa have been associated largely with El Niño. It can be expected that small changes in temperature and precipitation will support malaria epidemics at current altitudinal and latitudinal limits of transmission (Lindsay and Martens, 1998). Furthermore, flooding could facilitate breeding of malaria vectors and consequently malaria transmission in arid areas (Warsame *et al*., 1995). The Sahel region, which has suffered from drought in the past 30 years, has experienced a reduction in malaria transmission following the disappearance of suitable breeding habitats. Yet, there are risks of epidemics if flooding occurs (Faye *et al*., 1995).

Table 10-5*: Summary of number of countries in Africa reporting diseases/outbreaks from 1997 to July 1999.*[a] *Note that outbreaks indicate above-normal disease prevalence.*

Disease	1997	1998	1999 (Jan–July)
Malaria	0	2	2
Rift Valley fever	0	4	1
Yellow fever	1	1	0
Meningits	3	2	
Plague	2	1	2
Cholera	8	10	7
Dengue	0	0	0

[a] (WHO: Outbreak, <http://www.who.int/emc/outbreak_news/n1997/feb>). No reports were available for schistosomiasis, trypanosomiasis, onchocerciasis, and filariasis.

10.2.4.2. Cholera

Cholera is a water- and food-borne disease and has a complex mode of transmission. Flood causes contamination of public water supplies, and drought encourages unhygienic practices because of water shortage. The seventh pandemic currently is active across Asia, Africa, and South America.

Colwell (1996) demonstrates the link between cholera and SST. Upwelling of the sea as a result of increased SST increases the abundance of phytoplankton, which in turn supports a large population of zooplankton—which serves as a reservoir of cholera bacteria. Besides other epidemiological factors, the effects of SST on the spread of cholera may be the most profound because they affect large areas of the tropical seas and lakes. During the 1997–1998 El Niño, a rise in SSTand excessive flooding (WHO, 1998a) provided two conducive factors for cholera epidemics that were observed in Djibouti, Somalia, Kenya, Tanzania, and Mozambique—all lying along the Indian Ocean.

Cholera epidemics also have been observed in areas surrounding the Great Lakes in the Great Rift Valley region. Birmingham *et al.* (1997) found significant association between bathing, drinking water from Lake Tanganyika, and the risk of infection with cholera. Shapiro *et al.* (1999) have made a similar observation along the shores of Lake Victoria. It is likely that warming in these African lakes may cause conditions that increase the risk of cholera transmission. This is an area that urgently requires research. According to WHO (1998a), Africa accounted for 80% of the total reported number of cholera cases globally in 1997.

10.2.4.3. Meningitis

Major epidemics of meningococcal infections usually occur every 5–10 years within the African "meningitis belt;" they usually start in the middle of the dry season and end a few months later with the onset of the rains (Greenwood, 1984). Between February and April 1996, the disease affected thousands of people in parts of northern Nigeria, many of whom died (Angyo and Okpeh, 1997). This epidemic spread from the original meningitis belt to Kenya, Uganda, Rwanda, Zambia, and Tanzania (Hart and Cuevas, 1997). One of the environmental factors that predisposes to infection and epidemics is low humidity (Tikhomirov *et al.*, 1997). However, a climate-meningitis association was not clear in parts of the Gulf of Guinea (Besancenot *et al.*, 1997). That this disease has been limited to the semi-arid areas of Africa suggests that its transmission could be affected by warming and reduced precipitation.

10.2.4.4. Rift Valley Fever

From 1931 (when the disease was first described) until the end of the 1970s, Rift Valley fever (RVF) was considered to be a relatively benign zoonoses for humans that periodically developed in domestic animals (especially sheep) following heavy rains (Lefevre, 1997). Recent research indicates that although epizootics in east Africa are associated with an increase in rainfall, a similar association is unknown in west Africa (Zeller *et al.*, 1997). Recent data from west Africa indicate that the risk of a new epizootic is increasing in the region (Fontenille *et al.*, 1995), with significant exposure to the virus among livestock herders and wildlife rangers during the wet season (Olaleye *et al.*, 1996). Following the 1997–1998 El Niño event in east Africa, an RVF outbreak in Somalia and northern Kenya killed as much as 80% of the livestock and affected their owners (WHO, 1998b). Many cases also were reported in Tanzania. In Mauritania, the human epidemic was linked to the epizootic disease (Jouan *et al.*, 1989). Extensive research on mosquito vectors of RVF in Kenya (mainly *Aedes* and *Culex spp*.) has clearly linked the risk of outbreak with flooding (Linthicum *et al.*, 1990). It can be expected that increased precipitation as a consequence of climate change could increase the risk of infections in livestock and people. Such new risks could cause major economic and health problems for herding communities in Africa.

10.2.4.5. Plague

Plague is a flea-borne disease with rodents as reservoirs. The population of rodents can increase suddenly following heavy rains as a result of abundance of food (e.g., grain). During drought, rodents may migrate into human dwellings in search of food. Development of fleas and the pathogens they carry can be accelerated by increased temperature. Plague outbreaks recently have been reported in Mozambique, Namibia, Malawi, Zambia, and Uganda (see WHO Outbreak Web site: <www.who.int/disease-outbreak-news>).

10.2.4.6. Water-Associated Protozoal Diseases

Pollution of streams, wells, and other sources of rural water supplies by flooding could introduce parasites such as giardia, amoeba, and cryptosporidium into drinking water (Alterholf *et al.*, 1998). These parasites assume a new significance in HIV-infected individuals because of the latter's immunocompromised status (Mwachari *et al.*, 1998). Extreme weather events such as El Niño have been associated with increased episodes of diarrhea.

10.2.4.7. Other Major Parasitic Infections

Shifts in the epidemiology of schistosomiasis, onchocerciasis, and filariasis may take longer to become evident because these parasites are less sensitive to the effects of climate than diseases such as malaria. Changes in the impacts of climate on human trypnosomiasis may require substantial and permanent changes in tsetse fly ecology. Little or no data are available on this subject.

10.2.4.8. Air Pollution-Associated Diseases

Biomass burning and massive importation of badly maintained vehicles could result in increased air pollution—which, combined with increasing temperature, would exacerbate health risks such as respiratory problems and eye and skin infections (Boko, 1988).

10.2.4.9. Vulnerability

Evidence is emerging that many ecosystems on the African continent carry risks of climate-driven threats to human health. Predisposing factors include geographic location, socioeconomic status, and knowledge and attitude toward preventive measures. For example, populations living above 1,500 m in the east African highlands are at risk of epidemic malaria (Lindsay and Martens, 1998); those living along the shores of the Indian Ocean and the Great Lakes are at a risk of cholera infections when conditions for transmission are suitable (Birmingham *et al.*, 1997; Shapiro *et al.*, 1999).

Elsewhere in the Sahel and other arid areas where there are humidity deficits, populations are exposed to meningoccocal meningitis (Tikhomirov *et al.*, 1997) and, in flood-prone pastoral areas, RVF (Linthicum *et al.*, 1990). Vulnerability also can be increased by close habitation with animals that are reservoirs of zoonotic diseases such RVF and plague.

The socioeconomic status of communities may determine whether safe drinking water (piped water, rain-harvested water, and protected wells) is available (Sabwa and Githeko, 1985). The quality of housing is important because simple measures such as screening windows and doors will prevent the entry of disease vectors into human dwellings.

Human factors such as knowledge and attitude and practice will influence health care-seeking behavior of an individual (Karanja *et al.*, 1999). For example, individuals may choose to visit a local healer instead of a clinical facility, and this could affect the progression and outcome of an infection.

At the institutional level, the fragile infrastructure is unable to cope with the impacts of diseases. For example, flood areas often are inaccessible, and delivery of medical intervention is hampered considerably. Furthermore, pathogens such as those of malaria and cholera are resistant to commonly used medication. In the case of malaria, more than 60% of cases are treated at home (Reubush *et al.,* 1995) with drugs that may not be effective (Karanja *et al.*, 1999), particularly in nonimmune populations. Misdiagnoses of fevers, especially during epidemics of uncommon and unfamiliar diseases, leads to delayed treatment and consequently high morbidity and mortality (CDC, 1998). In many cases, foreign assistance is required, and this assistance may come too late. These factors increase the vulnerability of affected populations.

10.2.4.10.Adaptation

Understanding how climate affects the transmission of these diseases will lead to enhanced preparedness for early and effective interventions. Monitoring drug sensitivity to commonly used anti-malaria drugs and antibiotics will prevent the use of ineffective interventions. Communities that are exposed to water-borne diseases such as cholera could reduce the risk of infections by using safe drinking water technologies.

Several large-scale studies in Africa have demonstrated that insecticide-treated fabrics (e.g., bed-nets and curtains) can significantly reduce the risk of malaria infections (Lengeler, 1998). However, such interventions are not effective against day-biting mosquitoes that are vectors of RVF.

Remote sensing is increasingly becoming an important tool in forecasting the risks of transmission in malaria, RVF, and cholera. Hay *et al*. (1998) have shown that the normalized difference vegetation index (NDVI) correlated significantly with malaria presentation, with a lag period of 1 month. NDVI is a function of climatic factors that are similar to those that affect malaria transmission. Ability to use remote sensing to accurately detect parameters such as ground moisture that determine flooding could provide local officials with sufficient warning to allow for implementation of specific mosquito control measures before a disease (RVF) outbreak (Linthicum *et al*., 1990, 1999). In the case of cholera, it is now possible to utilize remote sensing and computer processing to integrate ecological, epidemiological, and remotely sensed spatial data for the purpose of developing predictive models of cholera outbreaks (Colwell, 1996).

10.2.4.11. Technology for Safe Drinking Water

Flooding, which can be exacerbated by climate change, often results in increased contamination of drinking water. In other instances, drought and an increase in surface water temperatures have been associated with transmission of cholera. Although Cryptosporidium parvum is the more important water-borne pathogen in developed countries, Vibrio cholerae is more pervasive in developing countries. Giardia lumbria, a water-borne protozoa, has a universal distribution. These pathogens pose serious threat to individuals whose immune systems are compromised; furthermore, there are numerous records of resistance to antibiotics by cholera bacteria (e.g., Weber *et al*., 1994). Therefore, it is essential that populations that are vulnerable to water-borne diseases should enhance safe drinking water technology.

Cryptosporidium parva oocytes are very resistant to chlorine and other drinking-water disinfectants (Venczel *et al*., 1997). In addition, the cysts have a very low sedimentation rate (Medema *et al*., 1998); consequently, boiling may be the most appropriate method of disinfecting water where risks of infection exist (Willocks *et al*., 1998). However, the use of submicron point-of-use water filters may reduce the risk of water-borne cryptosporidiasis (Addis *et al*., 1996).

Several simple and inexpensive techniques have been found to be effective in reducing the risk of infection with cholera from contaminated water. Huo *et al*. (1996) found that a simple filtration procedure involving the use of domestic sari material can reduce the number of cholera vibrio attached to plankton in raw water from ponds and rivers commonly used for drinking water. In Bolivia, the use of 5% calcium hypochlorite to disinfect water and subsequent storage of treated water in a narrow-mouthed jar produced drinking water from nonpotable sources that met WHO standards for microbiologic quality (Quick *et al*., 1996). In many cases, boiling water is not possible because of scarcity of firewood and charcoal, particularly in flooded conditions. These examples of low-cost technologies should become widely available to populations that are likely to be impacted by contaminated water supplies, especially following extreme flooding events.

10.2.5. Settlements and Infrastructure

10.2.5.1. Overview of Issues

The main challenges that are likely to face African populations will emanate from the effects of extreme events such as tropical storms, floods, landslides, wind, cold waves, droughts, and abnormal sea-level rises that are expected as a result of climate change. These events are likely to exacerbate management problems relating to pollution, sanitation, waste disposal, water supply, public health, infrastructure, and technologies of production (IPCC, 1996).

The pattern of distribution of human settlements often reflects the uneven nature of resource endowments and availability between regions and within individual communities. In Africa, as elsewhere, there are heavy concentrations of human settlements within 100 km of coastal zones (Singh *et al.*, 1999), in areas of high economic potential, in river and lake basins, in close proximity to major transportation routes, and in places that enjoy hospitable climatic regimes. Changes in climate conditions would have severe impacts not only on the pattern of distribution of human settlements but also on the quality of life in particular areas.

The transport sector is based on long-term, immovable infrastructure such as roads, rails, and water. Road networks have tended to link industrial centers with major areas of agricultural activity; railways have been designed primarily with a sea-route orientation to facilitate international shipments of primary products. Climate change may lead to industrial relocation, resulting either from sea-level rise in coastal-zone areas or from transitions in agroecological zones. If sea-level rise occurs, the effect on the many harbors and ports around the continent will be quite devastating economically for many coastal-zone countries. Excessive precipitation, which may occur in some parts of Africa, is likely to have serious negative effects on road networks and air transport.

10.2.5.2. Coastal Settlements and Sea-Level Rise

More than one-quarter of the population of Africa resides within 100 km of a sea coast (Singh *et al.,* 1999), rendering a significant number of people vulnerable to rises in sea level as a result of climate change. Modeling the effects of a 38-cm mean global sea-level rise in 2080, Nicholls *et al.* (1999) estimate that the average annual number of people in Africa impacted by flooding could increase from 1 million in 1990 to a worst case of 70 million in 2080. Jallow *et al.* (1999) estimate that the capital of The Gambia, Banjul, could disappear in 50–60 years through coastal erosion and sea-level rise, putting more than 42,000 people at risk. El Raey *et al.* (1999) discuss threats to coastal areas of Egypt from sea-level changes. East Africa coastal settlements also are at risk from sea-level rise (Magadza, 2000).

There are three response strategies to rising sea level and its physical impacts: retreat, adapt, or defend. Retreat can involve chaotic abandonment of property and cultural investments, or it can be an ordered, planned program that minimizes losses from rising sea level and maximizes the cost-effectiveness of the operation. The operation also seeks to leave surrendered areas as aesthetic looking as possible and to avoid abandoned structures that are an operational hazard to other social and economic activities.

The capacity of individual states to undertake coastal defense work may be limited. However, if such works are planned on a long-term time scale, it is possible to develop such defenses well before the crisis occurs and thus to spread the total capital costs over many years.

Because the problem of coastal management is regional, such a process would require:

- Regional integration among coastal-zone states
- Recognition by all governments in the region of regional vulnerability to climate change impacts
- Political and institutional stability that allows inter-generational projects to be sustained without interruption from political upheavals.

10.2.5.3. Flooding

Because of their combination of several natural resources, such as fisheries and fertile alluvial soils, wetlands and floodplains often are sites of dense rural settlements as well as urban settlements, such as N'Djamena near Lake Chad and coastal areas of southern Mozambique. The east Africa floods of 1998 and the Mozambique floods in early 2000 caused considerable damage to property and infrastructure. The major infrastructure damage was road and rail network damage. Communications among human settlements in Kenya, Uganda, Rwanda, and Tanzania were seriously disrupted, impeding movement of goods and persons in the region (Magadza, 2000). Many refugees could not be reached by land in Somalia, resulting in significant depletion of their food and medical supplies and leading to mortalities. Road and rail links to seaports were disrupted. In both instances, relief operations were hampered by difficulty of access to affected communities. In Mozambique, the floods of early 2000 caused approximately 2 million people to be displaced or severely affected; about 600 died (<http://www.reliefweb.int>, accessed October 10, 2000). By October 2000, the estimated cost of the Mozambique floods stood at more than US$167 million in terms of emergency aid funds during the flooding and in immediate activities to rehabilitate the infrastructure and relocate displaced persons. The impact on the national economy is still being evaluated but is expected to be significant.

One identifiable adaptive measure against extreme events that are climate related is a state of preparedness to give adequate warning of imminent danger and deliver relief. Facilities to broadcast timely information of developing events such as storms to rural populations remain weak. National disaster plans are available in some countries, but financial resources to respond to emergencies are lacking. The ability to convey impacts quickly to the international media is a factor in the speed and amount of relief. Recent events in Mozambique and other countries of southern and east Africa will provide useful lessons in dealing with similar disasters; there is great value in studying these events not only from the physical point of view—as the Climate Variability and Predictability Program (CLIVAR) is proposing in a new Africa program; see <http://www.dkrz.de/clivar/hp.html>—but also from the social point of view.

There is a need for better understanding of the hydrology of river basins to identify vulnerable areas and plan coping mechanisms. Management of early warning systems depends on good understanding of the dynamics of flood systems in real time.

Because river basins sometimes involve more than one state, as in the Somalia floods, an effective flood management protocol will call for international cooperation. A regular bulletin of flood development in Ethiopia would have given the coastal inhabitants of Somalia time to prepare for damage minimization. In the Mozambique floods of 1996–1997, for example, the trigger was heavy rains in the Shire River basin. If the Shire and Zambezi Rivers were managed as one basin system, it would have been possible to alleviate flooding in the Zambezi delta by manipulating Zambezi river flow, using the flood control capacity of Lakes Kariba and Kabora Bassa.

A further need in formulating adaptive strategies is more refined regional climate change scenarios—especially a better understanding of extreme events. In southern Africa, for example, most of the regional climate change scenarios are rather ambivalent with regard to precipitation (Hulme, 1996). In the 1998–1999 season, the city of Harare suffered damage to its roads because sewer transport could not cope with entrained stormwater. If it were accepted that the frequency of such seasons would increase, future designs of infrastructure amenities would take cognizance of that prediction.

10.2.5.4. Energy

Threats to energy security from climate change impacts are outlined in Section 10.2.1. Disruption of energy supplies will have ripple effects in the social fabric through impacts in economic activity. Some adaptation options for the energy needs of settlements in the African region are in three broad areas:

- Regional cooperation in sharing hydroelectric potential of the continent, especially that of the Zaire River
- More intensive use of renewable energy, such as solar and wind energy and biogas
- Efficient use of biomass.

The countries of the southern and central African region (Democratic Republic of the Congo, Zambia, Zimbabwe, Botswana, South Africa, Mozambique, Namibia) already are networked on an electric power grid system. Climate change models to date indicate minimum changes in the hydrology of the Congo basin, whereas other basins have significant vulnerability to climate change. A regional project to develop the hydropower potential of the Congo basin could significantly increase the energy security of the region without resort to GHG-emitting, coal-driven thermal power plants.

Alternatives to biomass are wind-driven units, either as direct application of wind force—as in water-pumping windmills—or for generation of electricity, as in the windmill farms of Denmark. Biogas units, which utilize livestock dung, have been demonstrated successfully in rural areas of Zimbabwe.

10.2.5.5. Human Comfort

McMichael *et al.* (1996) found a relationship between ambient temperature and heat-related mortalities in Cairo, Egypt. This suggests a need to consider building technology and building materials' thermal properties to produce dwellings that are naturally climatically comfortable for tropical conditions. In Africa, there is a tendency to construct dwellings that do not take account of local climate because of inadequate natural ventilation and use of large decorative glass surfaces. Similarly, urban planners need to consider landscaping to avoid inner-city congestion that leads to unhealthy microclimate enclaves.

A combination of high temperatures and air pollution leads to increases in respiratory complaints. Clean air policies would not only alleviate health hazards but would be a contribution toward maintenance of the ozone layer in line with the Montreal Protocol. Sudden imposition of stringent air quality standards may cause undue strain to the economy, but graduated improvement of air quality standards, at a pace the economy can absorb, will be beneficial in terms of adaptation to climate change as well as general city health improvement.

10.2.5.6. Water Resources

Section 10.2.1 argues that future water resources for subhumid regions of Africa will be in jeopardy under global warming conditions. The impact of climate change to settlements, through the water resources pathway, will have multiple manifestations in all walks of life.

Adaptive measures include incentives for a water conservation culture, such as water pricing. However, many rural communities are not economically or culturally attuned to commercialization of water resources, which normally are administered in a common access mode. Commoditization of water resources as a strategy for efficient water use is contingent on comparable growth of economic activity and social well-being in all sectors of communities.

Land degradation has resulted in siltation thus disappearance of surface streamwater resources (Magadza, 1984). States are encouraged to consider measures that will rehabilitate streams, paying special attention to wetlands conservation, with an added bonus of biodiversity conservation.

Industrial water cycling in Africa is poorly developed. Processes that maximize water recycling should be encouraged.

At the regional level, there are beginnings of cooperation in interbasin transfers from water-surplus areas to water-deficit areas; the proposed diversion of Zambezi River waters toward the south is an example. Although this development will enhance the status of water and other natural resources as tradable commodities, the groundwork for legal regulation of water sharing between nations of the region must be developed sooner rather than later to avoid situations of water-related political tensions like those in the Middle East and north Africa (Caponera, 1996).

10.2.5.7. Sanitation

Section 10.2.4 draws attention to the possible health implications of climate change and climate variability through vector- and water-borne pathogens. In many African urban settlements, urban drift has outpaced the capacity of municipal authorities to provide civic works for sanitation and other health delivery services. The outbreak of cholera during recent floods in east Africa and Mozambique underscores the need for adequate sanitation. It should be noted that although the outbreaks were spread from as far north as Mombassa and Nairobi in the north to Beira in the south, incidences remained localized to the outbreak centers because of the isolated nature of the affected urban areas. If settlement conglomerations such as those envisaged for west Africa and the eastern seaboard of South Africa develop—as discussed by Nicholls *et al*. (1999)—vulnerable population and areas will tend to be regional, rather than local. Review of sanitary facilities now rather than later will not only be beneficial to communities now but in the long run will be cost saving for long-term health delivery services.

10.2.5.8. Food Security

Droughts in SSA often translate to famine, which leads to acceleration of urban drift to cities that are not equipped to absorb such migrations. Although maintenance of strategic food reserves is one coping mechanism, development policies increasingly must create other investment opportunities in rural areas besides agriculture, to diversify means of survival and, indeed, create rural wealth (De Lattre, 1988).

In semi-arid Africa, pastoralism is the main economic activity. Many pastoral communities include transnational migrants in search of new seasonal grazing. In drought situations, such pastoralists may come into conflict with settled agrarian systems (Anon, 1992; Lado, 1995; Cousins, 1996). Students of pastoralism note the lack of clear policies on pastoralists, who normally are marginalized in state agricultural policies.

10.2.6. Desertification

10.2.6.1. Context

The United Nations Convention to Combat Desertification (UNCCD) defines desertification as “land degradation in arid, semi-arid, and dry subhumid areas resulting from various factors, including climatic variations and human activities” (United Nations, 1994). Furthermore, UNCCD defines land degradation as a “reduction or loss, in arid, semi-arid, and dry subhumid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation.”

Arid, semi-arid, and dry subhumid areas include those lands where the ratio of precipitation to potential evaporation (PET) ranges from 0.05 to 0.65. In Africa, these conditions cover 13 million km^2 (see Figure 10-9), or 43% of the continent’s land area—on which 270 million people, or 40% of the continent’s population, live (UNDP, 1997). Areas particularly at risk include the Sahel—a 3.5 million km^2 band of semi-arid lands stretching along the southern margin of the Sahara Desert—and some nations that consist entirely of drylands (e.g., Botswana and Eritrea). The death of as many as 250,000 people in the Sahel drought of 1968–1973 (UNCOD, 1977) demonstrated the tragic human toll of desertification.

Desertification in Africa has reduced by 25% the potential vegetative productivity of more than 7 million km^2, or one-quarter of the continent’s land area (UNEP, 1997). Desertification consists more of degradation of the productive capacity of patches well outside open-sand deserts rather than the inexorable encroachment of open sand onto greenlands. Arid lands can respond quickly to seasonal fluctuations. Indeed, analysis of 1980–1990 NDVI data to track the limit of vegetative growth along the Sahara-Sahel margin revealed wide fluctuations: The 1990 limit of vegetative growth lay 130 km south of its 1980 position (Tucker *et al*., 1991).

Unfortunately, the relative importance of climatic (see Section 10.2.6.3) and anthropogenic (see Section 10.2.6.2) factors in causing desertification remains unresolved. Some scientists have judged that anthropogenic factors outweigh climatic factors (Depierre and Gillet, 1971; Lamprey, 1975; Le Houérou, 1989; Westing, 1994), though others maintain that extended droughts remain the key factor (Mortimore, 1989; Hoffman and Cowling, 1990; Tucker *et al*., 1991; Dodd, 1994). CO_2-induced climate change and desertification remain inextricably linked because of feedbacks between land degradation and precipitation (see Section 10.2.6.4).

10.2.6.2. Nonclimatic Driving Forces of Desertification

Unsustainable agricultural practices, overgrazing, and deforestation constitute the major anthropogenic factors among the forces that drive desertification. Unsustainable agricultural practices include short rotation of export crops, undisciplined use of fire, and removal of protective crop residues. Overgrazing consists of running livestock at higher densities or shorter rotations than an ecosystem sustainably can support. Finally, deforestation consists of permanent clearing of closed-canopy forests and cutting of single trees outside forests. Forest area in Africa decreased by approximately 37,000 km^2 yr^{-1} from 1990 to 1995 (FAO, 1999a). UNEP (1997) attributes two-thirds of the area already desertified in Africa to overgrazing and the remaining third to unsustainable agricultural and forestry practices.

Population growth ultimately can drive desertification if it intensifies agrosylvopastoral exploitation or if it increases the land area subjected to unsustainable agricultural practices, overgrazing, or deforestation. The total population of Africa grew from 220 million in 1950 to 750 million in 1998—a rate of 2.5% yr^{-1} (United Nations, 1999). Increasing food, wood, and forage needs accompanying this growth place an inordinate burden on the region’s natural resources.

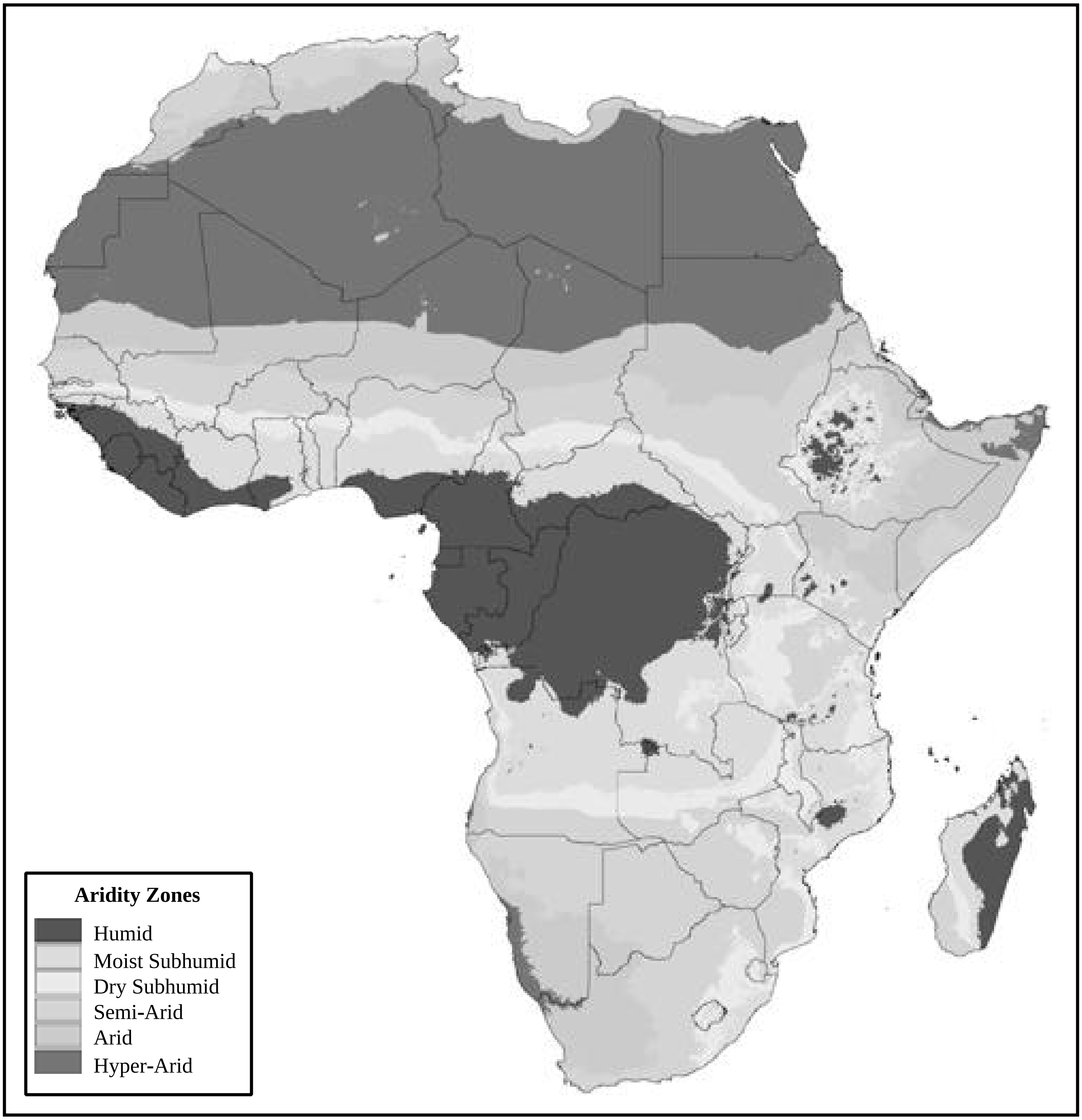

Figure 10-9: Aridity zones for Africa as derived from mean monthly precipitation and potential evapotranspiration surfaces included on *Spatial Characterization Tool for Africa* CD-ROM (UNDP, 1997).

10.2.6.3. Climatic Factors in Desertification

Precipitation and temperature determine the potential distribution of terrestrial vegetation and constitute principal factors in the genesis and evolution of soil. Extended droughts in certain arid lands have initiated or exacerbated desertification. In the past 25 years, the Sahel has experienced the most substantial and sustained decline in rainfall recorded anywhere in the world within the period of instrumental measurements (Hulme and Kelly, 1997). Linear regression of 1901–1990 rainfall data from 24 stations in the west African Sahel yields a negative slope amounting to a decline of 1.9 standard deviations in the period 1950–1985 (Nicholson and Palao, 1993). Since 1971, the average of all stations fell below the 89-year average and showed a persistent downward trend since 1951.

Because evapotranspiration constitutes the only local input to the hydrological cycle in areas without surface water, reduction in vegetative cover may lead to reduced precipitation, initiating a positive feedback cycle. Degradation of vegetation cover in moister areas south of the Sahel may have decreased continental evapotranspiration and reduced precipitation in the Sahel (Xue, 1997).

A positive feedback mechanism between vegetation cover and albedo may help to explain the Sahel drought (Charney, 1975). Some research supports an albedo-precipitation feedback mechanism (Otterman, 1974; Cunnington and Rowntree, 1986; Xue *et al*., 1990; Diedhiou and Mahfouf, 1996; Zheng and Eltahir, 1997; Zeng *et al.,* 1999), although other research disputes the importance of albedo (Jackson and Idso, 1974; Ripley, 1976; Wendler and Eaton, 1983; Gornitz and NASA, 1985; Nicholson *et al*., 1998; Nicholson, 2000).

Degraded land also may increase atmospheric dust and aerosols, which influence precipitation (see Section 10.1.3.2).

SSTanomalies, often related to ENSO or NAO, also contribute to rainfall variability in the Sahel (Lamb, 1978; Folland *et al*., 1986; Hulme and Kelly, 1997; Nicholson and Kim, 1997; Hulme *et al*., 1999). Lamb (1978) observes that droughts in west Africa correlate with warm SST in the tropical south Atlantic. Examining oceanographic and meteorological data from the period 1901–1985, Folland *et al*. (1986) found that persistent wet and dry periods in the Sahel were related to contrasting patterns of SSTanomalies on a near-global scale. When northern hemisphere oceans were cold, rainfall in the Sahel was low.

Street-Perrott and Perrott (1990) demonstrate that injections of freshwater into the north Atlantic (such as from glacial melt) decrease salinity—stabilizing the water column, inhibiting deep convection, and reducing northern transport of heat by the Atlantic thermohaline circulation, which is driven by a north-south SST gradient. This decreases evaporation from the ocean surface, causing drought in the Sahel and Mexico. From 1982 to 1990, Mynemi *et al*. (1996) found a correlation between ENSO-cycle SST anomalies and vegetative production in Africa. They found that warmer eastern equatorial Pacific waters during ENSO episodes correlated with rainfall of <1,000 mm yr^{-1} over certain African regions.

A combination of factors—including vegetation cover, soil moisture, and SST—best explains the reduction in rainfall in the Sahel. Diedhiou and Mahfouf (1996) modeled changes in albedo, soil moisture, land surface roughness, and SST anomalies and calculated a rainfall deficit over the Sahel similar to observed patterns. Eltahir and Gong (1996) suggest that a meridional distribution of boundary-layer entropy regulates the dynamics of monsoon circulation over west Africa, explaining observed correlations of SST to rainfall and the sensitivity of monsoon circulation to land-cover changes. A coupled surface-atmosphere model indicates that—whether anthropogenic factors or changes in SST initiated the Sahel drought of 1968–1973—permanent loss of Sahel savanna vegetation would permit drought conditions to persist (Wang and Eltahir, 2000). Zeng *et al.* (1999) compared actual rainfall data from the period 1950–1998 with the output of a coupled atmosphere-land-vegetation model incorporating SST, soil moisture, and vegetative cover. Their results indicate that actual rainfall anomalies are only weakly correlated to SST by itself. Only when the model includes variations in vegetative cover and soil moisture does it come close to matching actual rainfall data. Modeling the importance of SST, sea ice, and vegetative cover to the abrupt desertification of the Sahara 4,000–6,000 years ago, Claussen *et al.* (1999) show that changes in vegetative cover best explain changes in temperature and precipitation.

10.2.6.4. Linkages and Feedbacks between Desertification and Climate

CO_2-induced climate change might exacerbate desertification through alteration of spatial and temporal patterns in temperature, rainfall, solar insolation, and winds. Conversely, desertification aggravates CO_2-induced climate change through the release of CO_2 from cleared and dead vegetation and through the reduction of the carbon sequestration potential of desertified land.

Areas that experience reduced rainfall and increased temperature as a result of CO_2-induced climate change also could experience declines in agricultural yields, livestock yields, and tree cover, placing local people at risk of famine.

Lower soil moisture and sparser vegetative cover also would leave soil more susceptible to wind erosion. Reduction of organic matter inputs and increased oxidation of soil organic matter (SOM) could reduce the long-term water-retention capacity of soil, exacerbating desertification. Sample plots in Niger lost 46 t ha^{-1} in just four windstorms in 1993 (Sterk *et al.,* 1996), releasing 180 ± 80 kg ha^{-1} yr^{-1} of soil carbon (Buerkert *et al.,* 1996). Moreover, increased wind erosion increases wind-blown mineral dust, which may increase absorption of radiation in the atmosphere (Nicholson and Kim, 1997).

Desertification from anthropogenic and climatic factors in Senegal caused a fall in standing-wood biomass of 26 kg C ha^{-1} yr^{-1} in the period 1956–1993, releasing carbon at the rate of 60 kg C cap^{-1} yr^{-1} (Gonzalez, 1997).

Although altered surface albedo may increase surface air temperatures locally (Williams and Balling, 1996), the effect of desertification on global mean temperature is unlikely to have exceeded 0.05°C in the past century (Hulme and Kelly, 1997).

10.2.6.5. Impacts of Desertification

Desertification reduces soil fertility, particularly base cation content, organic matter content, pore space, and water-retention capacity. Desertification also reduces vegetative productivity, leading to long-term declines in agricultural yields, livestock yields, plant standing biomass, and plant biodiversity. These changes reduce the ability of the land to support people, often sparking an exodus of rural people to urban areas. Breaking the strong connection of people to the land produces profound changes in social structure, cultural identity, and political stability.

In Niger, on farmed land where organic carbon in the top 10 cm of the soil has fallen from 0.3 to 0.2% 4 years after coming out of fallow, millet yields fell from 280 to 75 kg ha^{-1} (Bationo *et al.*, 1993). Modeling of the 4,000 km^2 Mgeni River watershed in South Africa showed that conversion of more than one-quarter of the watershed from forest and rangeland to agriculture and exotic tree plantations since the area was colonized would double mean annual runoff in urban areas and other areas of reduced land cover (Schulze, 2000).

In the Senegal Sahel, the densities of trees with a height of >3 m declined from 10 trees ha^{-1} in 1954 to 7.8 trees ha^{-1} in 1989; the species richness of trees and shrubs fell from 16 species per 4 km^{-2} around 1945 to about 11 per 4 km^{-2} in 1993 (Gonzalez, 1997, 2001). These changes have caused a 25–30 km shift of the Sahel, Sudan, and Guinean vegetation zones in half a century, proceeding at an average rate of 500–600 m yr^{-1}. Arid Sahel species expanded in the northeast, tracking a concomitant retraction of mesic Sudan and Guinean species toward areas of higher rainfall and lower temperature to the southwest.

In the Senegal Sahel, human carrying capacity in 1993 stood at approximately 13 people km^{-2} at observed patterns of resource use, compared to an actual 1988 rural population density of 45 people km^{-2} (Gonzalez, 1997, 2001). This means that people with no other alternatives need to cut into their natural resource capital to survive. Such changes across Africa have pushed a rural exodus that may have displaced 3% of the population of Africa since the 1960s (Westing, 1994).

Desertification also will cause conversion of perennial grasslands to savannas dominated by annual grasses. Such changes have occurred in the Kalahari Gemsbok National Park in South Africa, where Landsat imagery showed increases in exposed soil surface (Palmer and van Rooyen, 1998). Such declines often are irreversible (Schlesinger *et al*., 1990).

10.2.6.6. Vulnerability and Adaptation

The tragic death of as many as 250,000 people in the Sahel drought of 1968–1973 (UNCOD, 1977) demonstrates the vulnerability of humans to desertification. As desertification proceeds, agricultural and livestock yields decline, reducing people's options for survival. Furthermore, not only do local people lose the vital ecosystem services that dead trees and shrubs had provided; the loss of firewood, traditional medicine species, and emergency food species render them more vulnerable to future environmental change.

Adaptations by farmers and herders in Africa to climate change and desertification have involved diversification and intensification of resource use (Davies, 1996; Downing *et al.*, 1997). Resourceful diversification responses by women in Bambara and Fulbe households in Mali (Adams *et al.*, 1998) reflect the importance of women in guiding adaptation strategies across Africa. In southern Kenya, Maasai herders have adopted farming as a supplement to or replacement for livestock herding (Campbell, 1999). In Kano, Nigeria, peri-urban vegetable gardening has expanded (Adams and Mortimore, 1997), revealing a common diversification trend in small cities across west Africa. In northern Cameroon, Fulbe herders have increased the number of herd displacements between pasture areas and even resorted to long-distance migration, sometimes introducing significant changes to their way of life (Pamo, 1998).

In the future, seasonal climate forecasting (NOAA, 1999; Stern and Easterling, 1999) may assist farmers and herders to know times of higher probability of success of resource diversification or intensification. Seasonal forecasts for Africa currently exhibit moderate skill levels (Thiaw *et al.*, 1999) but skill levels and user communications are not yet high enough to permit users to confidently implement field applications (UNSO, 1999; Broad and Agrawala, 2000). Neither trade nor technology will likely avert the widespread nutritional and economic effects of desertification through the 2020s (Scherr, 1999).

Other adaptations to desertification involve more efficient management of resources. In Niger, farmers with access to credit will adopt low-cost, appropriate technologies for wind erosion control, including windbreaks, mulching, ridging, and rock bunds (Baidu-Forson and Napier, 1998). Across Africa, farmers traditionally have adapted to harsh environmental conditions by promoting natural regeneration of local trees and shrubs. Natural regeneration is a practice whereby farmers and herders seek to reconstitute vegetative cover by setting aside parcels of land or by selecting valued trees in their fields, pruning them, straightening them, and raising them to maturity. The Sereer in Senegal (Lericollais, 1973) and the Mossi in Burkina Faso (Kessler, 1992) have achieved doubling of tree densities in certain semi-arid areas with *Acacia albida* and *Butyrospermum parkii*, respectively.

10.3. Adaptation Potential and Vulnerability

The foregoing assessment highlights the high vulnerability of Africa to climate change as a result of limited adaptive capacity constrained by numerous factors at the national level. The floods of February 2000 in southern Africa (which affected Mozambique, South Africa, Botswana, and Zimbabwe) highlight huge differences in adaptive capacities between countries. Adaptive capacity was influenced largely by the ability to communicate potential risks to vulnerable communities and the ability to react as a result of perceived risks. The ability to mobilize emergency evacuation was critical in reducing adverse impacts. Although there may be high adaptive capacity locally or nationally, overall most countries in Africa have low capacity to adapt to abrupt and extreme events.

Scarce water resources are becoming increasingly critical for Africa; they determine food security as well as human and ecosystem health, and play a major role in political and socioeconomic development. Although parts of Africa have abundant water, shifting water to stressed areas is not an option in many cases. Groundwater resources are likely to be impacted by prolonged droughts and changes in land cover and land use, in a complex interaction of human activity and population growth rates, climate, and environmental responses. Adaptation will require small actions as well as major national approaches. At the management unit level (e.g., watershed), careful management of rainwater through damming will allow agricultural production. There is vast experience in arid regions of Africa such as Namibia, Botswana, and north Africa (such as Morocco), where brief periods of rain are utilized very efficiently for farming. The constraint will be in finding limits to water extraction that do not adversely impact communities downstream and result in conflicts. Regional bodies set up to negotiate international water rights will play an increasingly crucial role. At the national level, political goals such as self-sufficiency in food production will need to be reevaluated with reference to water resources available to the country and how they can be apportioned between food production, human needs, and ecosystem needs. Countries will need to be more open to fulfilling their food needs through imports and redistribution, using intensified production in areas where it is possible. Good communications within and between countries and major ports are critical to food security. These include roads, rail, and air transportation networks. For inland countries, large corridors being opened up or upgraded (such as the Maputo, Nacala, and Beira corridors between Mozambique and South Africa, Malawi, and Zimbabwe) will greatly enhance access to food and other imported goods. This places greater importance on international relations.

At the subregional scale, Africa is vulnerable to ENSO and related extreme events (drought, floods, changed patterns). As shown by Semazzi and Song (2000), deforestation is likely to alter circulations in distant places through teleconnected feedbacks, increasing the vulnerability of distant populations. Advances in seasonal forecasting, using climate models and satellite observations, has been shown to be a first-order response strategy to changing climate variability. Similar applications of satellite observations (such as for SST) also are useful in predicting disease outbreaks such as RVF. Effective communication of predicted extreme weather events and evaluation of potential risks is critical in minimizing human loss of life, where it is possible to react. Disaster management plans are required and need to be developed jointly with all members of a community.

There is great potential in investing in seasonal forecasting and development of tools (models) such as crop models that can be used to make adjustments in management. Although these models are still experimental, they offer a realistic response to changing climatic patterns. Data must be collected to calibrate and validate these models. In the longer term, governments will need to develop strategic plans that are based on solid foundations. This is an area that is underdeveloped in almost all of Africa.

External funding drives programs in many African countries, so agendas usually align closely with donor agency interests. This situation presents a dilemma for Africa. There is capacity in many countries now to evaluate effective strategies to adapt to adverse effects of climate change. However, these countries are at the mercy of donor agency representatives who often are less informed about issues of climate change. These representatives often regard immediate problems of poverty, erosion, health, and empowerment as the only priority issues for Africa. Longer term planning—for example, land-use planning in areas that are susceptible to flooding under infrequent cyclonic events—never receives the attention it deserves. Most African countries are unlikely to motivate internal funding for climate change; therefore, it is critical that funding agencies award high visibility to issues of climate change.

10.4. Synthesis

Select key impacts over the African continent are highlighted in Figure 10-10. Water resources are a key vulnerability in Africa for water supply for household use and for agricultural and industrial use. In shared river basins, regional cooperation protocols minimize adverse impacts and potential for conflicts. Land use in many of Africa's large and shared basins has long-lasting impacts through modifications of the water budget and through chemical and sediment input into waterways. Water issues in urban and rural areas are likely to become more critical, given increasing and competing demands, as well as rapid population growth. Infrastructure to store and serve water in major urban areas is mostly overstretched in capacity, and extreme events such as floods that cause physical damage add to the problem. Monitoring of water levels and water use is very poor and limits analysis of vulnerability.

There is wide consensus that climate change will worsen food security, mainly through increased extremes and temporal/spatial shifts. The continent already experiences a major deficit in food production in many areas, and potential declines in soil moisture will be an added burden. Food-insecure countries are at greater risk of adverse impacts of climate change.

Irreversible losses of biodiversity could be accelerated with climate change. Climate change is expected to lead to biome shifts, with drastic shifts of biodiversity-rich biomes such as the Succulent Karoo in South Africa, and many losses in species in other biomes. Analysis of potential biome shifts is possible in areas where good spatial databases of vegetation and biophysical variables and land use are available. It is expected that these analyses will improve as more data are available from new and better satellite sensing systems, as well as coordinated field studies in shared resource areas.

Changes in temperature and rainfall will have many negative impacts on human health. Changes in disease vector habitats will expose new populations to diseases such as malaria. Droughts and flooding, where sanitary infrastructure is inadequate, will result in increased frequency of water-borne diseases. Increased rainfall could lead to more frequent outbreaks of RVF. Many African nations do not have adequate financial resources for public health.

Sea-level rise, coastal erosion, saltwater intrusion, and flooding will have significant impacts for African communities and economies. Most of Africa's largest cities are along coasts and are highly vulnerable to extreme events, sea-level rise, and coastal erosion as a result of inadequate physical planning and escalating urban drift. Rapid unplanned expansion is likely to predispose large populations to infectious diseases from climate-related factors such as flooding.

Desertification is a critical threat to sustainable resource management in arid, semi-arid, and dry subhumid regions of Africa, undermining food and water security.

A diversity of constraints facing many nations limits overall adaptive capacity for Africa. Although there is uncertainty about what the future holds, Africa must start planning now to adapt to climate change. Current technologies and approaches—especially in agriculture and water—are unlikely to be adequate to meet projected demands, and increased climate variability will be an additional stress. It is unlikely that African countries on their own will have sufficient resources to respond effectively.

Climate change also offers some opportunities. The processes of adapting to global climate change, including technology transfer and carbon sequestration, offer new development pathways that could take advantage of Africa's resources and human potential. Regional cooperation in science, resource management, and development already are increasing, and access to international markets will diversify economies and increase food security.

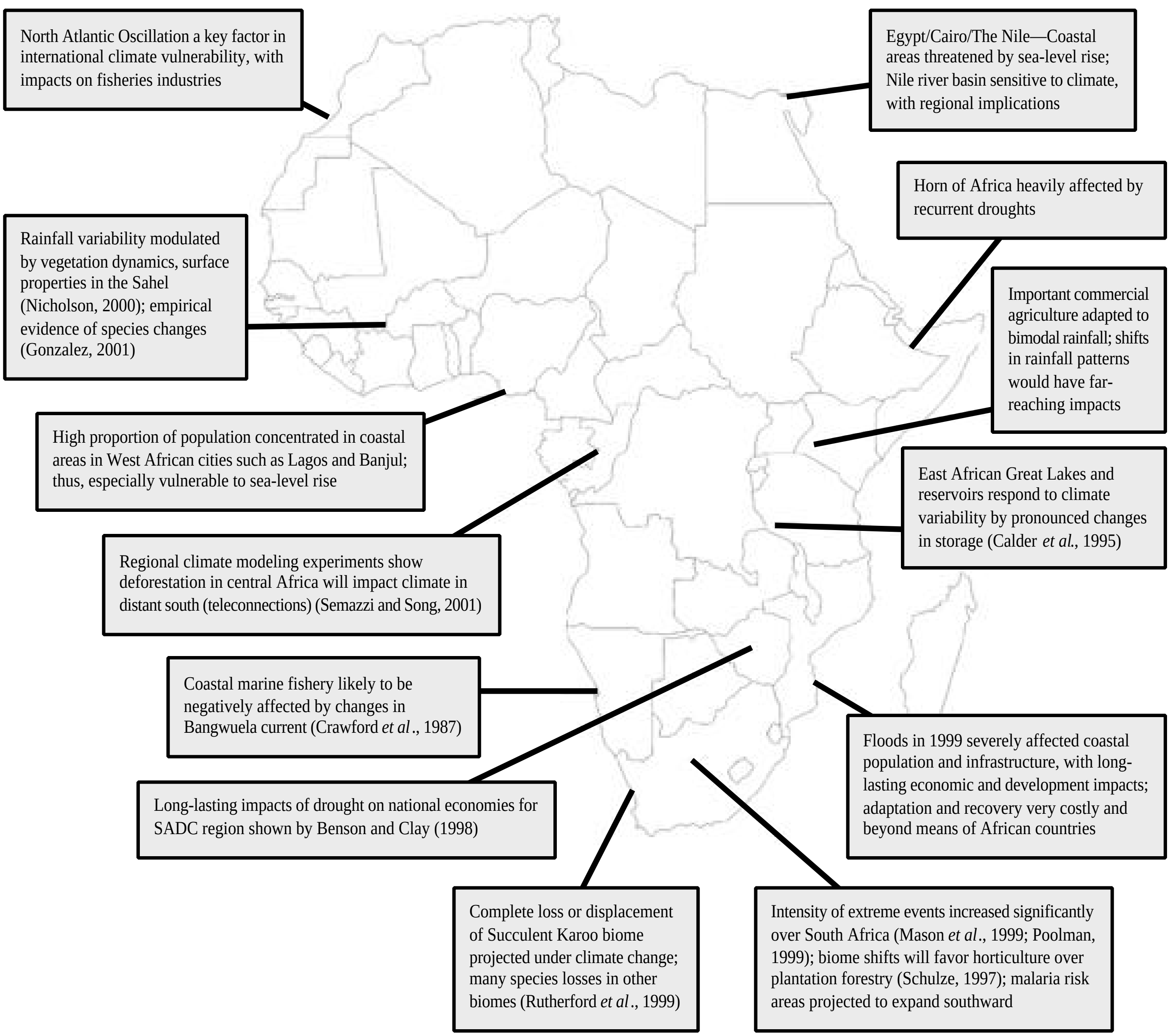

Figure 10-10: Selected key impacts for Africa.

10.4.1. Feedbacks and Interactions

Several integrated studies have looked at feedbacks and complex interactions in African regional systems. In the west African Sahel, land surface-atmosphere interactions have been examined in great detail to explore their role in interannual variability of rainfall since the long drought that started in the late 1960s. Reviews by Nicholson (2000) and Hunt (2000) summarize the state of knoweldge for the physical climate of the Sahel. In general, surface processes modulate rainfall variability, along with SST—but in complex ways. The Sahel is likely to remain a major study topic, and field-based observational studies are on the rise. A field campaign in 1992 called the Hydrologic Atmosphere Pilot Experiment (HAPEX)–Sahel was designed to find ways of improving modeling of land surface properties; a series of HAPEX-Sahel papers were published in a special issue of the *Journal of Hydrology* (Goutourbe *et al*., 1997). More recently, a regional land-atmosphere experiment is underway in southern Africa to study fires and emissions, with modeling studies planned to explore land-atmosphere linkages (see <http://safari.gecp.virginia.edu>, accessed October 2000). These studies—and integrated modeling in general—offer comprehensive tools for studying the integrated Earth system. More studies of this kind will assist in our understanding of linkages between land surface processes, regional and global linkages, and human activities.

Biomass burning plays an important role in global atmospheric chemistry (Andreae, 1991), particularly with respect to generation of trace gases that lead to the formation of tropospheric O_3, carbon monoxide (CO), nitrogen oxides, CH_4, volatile organic carbon (VOC, which also is a GHG), and smoke particles (aerosols), which have an anti-greenhouse effect. Africa is a significant location of biomass burning. In Africa, there are three main types of biomass fires: those associated with land clearing for agriculture, which are mostly located in humid tropical forests and the subhumid tropics; burning of wood for domestic energy (either directly or after first converting it to charcoal); and fires in natural and semi-natural vegetation, which are not associated with changes in land cover or use. Emissions from all three types are of broadly comparable magnitude (Scholes and Scholes, 1998), although the last category has received the most attention.

Fires in natural vegetation are not considered to be a net source or sink in the global carbon cycle because when integrated over large regions and over several years, CO_2 (as well as CO, CH_4, and VOC, which ultimately converts to CO_2) emitted by the fire is taken up again by vegetation regrowth. This is true if the overall fire frequency or intensity is not changing, but if fires become more frequent or consume more fuel over time, the result will be a net CO_2 source; conversely, if fire frequency is reduced or the fires burn less fuel, a carbon sink will result, manifested as an increase in woody biomass. There is no evidence that at a contental scale, fires in natural vegetation have increased or decreased in frequency or intensity in the historic period. For some subregions (such as parts of southern and east Africa), where there is clear thickening of the woody vegetation, it is likely that fire regimes have become less frequent and intense during the 20th century.

During years of regional drought, such as those in southern Africa associated with El Niño events, the area burned decreases by about half (Justice *et al.*, 1996). It is believed that this is caused principally by a decrease in fuel availability.

The potential for teleconnections in impacts of land-use change on distant climates further increases the risk in communities that may be at low risk but will be impacted by actions taken in distant areas. For example, deforestation of the central African basin leads to climatic impacts in the savannas to the south in GCM modeling experiments (Semazzi and Song, 2001).

It is clear that rainfall (e.g., intensity) combined with land-use conversion in watershed areas leads to increased soil erosion. Enhanced siltation in rivers and increased use of chemicals also leaching into the runoff interferes with river chemistry (e.g., eutrophication), with major implications for water quality in lakes and coastal systems. Impacts on biodiversity—hence important economic fisheries, and consequent feedback on national economies—is an area of research that needs elucidation.

10.4.2. Uncertainties and Risks

There is great uncertainty about how climate might change at subregional scales in parts of Africa, especially how this might be influenced by human-driven factors such as deforestation and alternative land uses. Regional climate modeling will help reduce these uncertainties, and there are early results now of such modeling for parts of Africa. For these results to be useful, they will have to incorporate realistic disturbance regimes (e.g., realistic deforestation mechanisms and land-use characterizations).

Climate change will manifest itself through changes in climate variability and hence changes in extreme events. Given its socioeconomic status, Africa is unlikely to respond any better to extreme events than it has in the past. Flooding, droughts, and so forth are increasingly difficult for Africa to cope with given increasing pressures on resources from rapid population growth and dwindling resources. Most African countries remain largely unable to gather adequate data and information in a timely manner to address critical problems and surprises such as droughts and floods. Although progress is being made to design environmental information systems, models for analyzing impacts and policy options are largely nonexistent. Although adequate data probably exist, what is needed is the capacity to access large amounts of data and synthesize it into useful bits of information for decisionmaking. For example, satellite data have been collected over the past 2 to 3 decades, yet their use is largely restricted to mapping and short-term climate predictions. Effective information systems and monitoring have not been achieved.

Evaluation of impacts in monetary or other quantitative terms remains a major obstacle to comprehensive assessment of impacts of climate change for Africa. Regional integrated assessment modeling, such as in Egypt (Yates and Strzepek, 1998), offers a solution, and model development should be accelerated for subregions of Africa where building blocks exist (Desanker *et al.*, 2001).

ENSO-related impacts remain uncertain, given perceived changes in ENSO events in terms of frequency and duration. However, much progress is being reported in prediction of ENSO, and this information should be closely linked with case studies of how different regions and populations respond to specific climate-related events. These studies should document costs and benefits, as well as responses.

10.4.3. Cross-Cutting Issues

10.4.3.1. Costing

In some of the sectors affected by climate change—such as water resources, food security, and natural resources—it may be possible to attach financial values. At this point, there are few if any published data on the economic impacts of climate change on these sectors in Africa. However, there are indications of what it costs to support communities that have been affected by famine and floods. Because most of this is foreign aid, it is difficult to evaluate costs in relation to individual country economies. There are indications that water shortages have a negative impact on power generation and consequently economic activities. It is acknowledged that some elements such as health are difficult to cost. Nevertheless, the financial impacts of dealing with epidemics such as malaria, menengitis, and cholera are known by various governments. Governments may be able to translate the impacts described in this assessment to national costs and begin to plan how to develop adaptive financial measures. As methods for impact assessment involve more integrated modeling, it will be possible to quantify impacts of specific climate change scenarios, either in terms of goods and services or in monetary terms.

10.4.3.2. Development, Sustainability, and Equity

The great uncertainty is the political development of Africa. Africa has had its share of surprises in the political arena. What appeared to be a steady march to economic growth would be shattered by sudden political upheavals and festering corruption among national leadership, which tends to have a trickle-down effect until the process of governance is corrupted at its core. On the other hand, the sudden collapse of apartheid in South Africa brought a fresh wind of hope in southern Africa, with far-reaching impacts on the rest of the continent. The adaptive recommendations made in this assessment assume an underpinning of good governance and social responsibility. Achebe *et al.* (1990) tackle the issue of Africa's future political and economic demise. Using various approaches and assumptions, they conclude that Africa may not enjoy political and economic stability prior to 2020–2030 at the earliest. According to climate change impact scenarios, this is the period when climate impacts will have significant impacts on the economic and social fabric. Thus, the message is that Africa must get its house in order as a matter of urgency. We challenge the African political leadership to belie the Achebe *et al.* (1990) prognosis.

The impacts of climate change are expected to be severe, yet Africa's contribution to climate change through emissions is minimal. There are strong feelings among some people in the South who would like to see the North implement tangible emissions reductions and find ways of helping the South adapt to adverse impacts of climate change. From this synthesis, it is clear that Africa is highly vulnerable, with very low capacity to adapt. There is great potential to transfer technology to Africa that would help in developing sustainable agriculture, as well as other technologies that would assist in improving welfare and economic development.

Although the relative importance of climatic and anthropogenic factors in causing desertification remains unresolved, evidence shows that certain arid, semi-arid, and dry subhumid areas have experienced declines in rainfall, resulting in decreases in soil fertility and agricultural, livestock, forest, and rangeland production. Ultimately, these adverse impacts lead to political and socioeconomic instability.

Given the range and magnitude of development constraints and challenges facing most African nations, the overall capacity for Africa to adapt to climate change is low. Although there is uncertainty about what the future holds, Africa must start planning now to adapt to climate change. National environmental action plans and their implementation need to incorporate long-term changes and pursue "no regret" strategies. Current technologies and approaches—especially in agriculture and water—are unlikely to be adequate to meet projected demands, and increased climate variability will be an additional stress. Seasonal forecasting—for example, linking SSTto outbreaks of diseases—is a promising adaptive strategy that will help to save lives.

Climate change offers some opportunities for development. The process of adapting to global climate change, including technology transfer, offers new development pathways that could take advantage of Africa's resources and human potential. Examples would include competitive agricultural products, resulting from research in new crop varieties and increased international trade, and industrial developments such as solar energy. Regional cooperation in science, resource management, and development already is increasing.

This assessment of vulnerability to climate change is marked by uncertainty. The diversity of African climates, high rainfall variability, and a very sparse observational network make predictions of future climate change difficult at the subregional and local levels. Underlying exposure and vulnerability to climatic changes are well established. Sensitivity to climatic variations is established but incomplete. However, uncertainty about future conditions means that there is low confidence in projected costs of climate change.

10.4.4. Future Needs

Issues related to Africa's capacity to understand projected impacts include:

- *Data Needs:* The potential exists to develop environmental information systems on the basis of satellite data products and geographic information systems at small management units such as river basins, with socioeconomic and biophysical attributes as required in analyses of impacts and management. Current impact assessment models are limited by input data, limiting their use to fairly general questions. Examples exist where detailed spatial databases have been built and are being used to run integrated agrohydrological models, such as in South Africa (Schulze, 1997; Schulze and Perks, 2000). Monitoring of environmental processes as well as increased weather observation are required. Coordinated collection of integrated data sets for subregions or in connection with an extreme event such as a drought or a flood is highly desirable and would contribute to understanding of adaptation and response strategies and regional integrated modeling.
- *Human Capacity:* There is great need for increased African capacity to study the more fundamental science issues of global change and its impacts. There is great capacity at the applied management level in Africa, and this must be strengthened by a strong science capacity. The increasing number of international environmental treaties and agreements will require an even greater capacity for analysis and delivery of timely reports. There also is great need to apply science findings in policy analysis and international negotiations.
- *Integrated Analysis:* It is becoming increasingly clear that most environmental problems such as climate change require integration of many disciplines and methods of analysis. There also is a shift in interest and focus from global scales to regional and local scales. Models that help to integrate science findings with management and policy issues are needed. These models, called integrated assessment models, are required at regional and subregional levels and should include all important linkages between the socioecological and economic sectors. Given the unique combinations of factors in subregions of Africa (climate, economics, infrastructure), it will be necessary in future assessments to develop and apply regional assessment models that reflect key factors for each subregion, and these models will need to be built around issues of sustainable development rather than emissions reduction. Linking climate change (and other environmental issues) to sustainable development is not going to be easy, but it should spawn a rich body of research to define methods and approaches that will work.
- *Literature Written in French:* It is recognized that there is a rich body of literature that is written in French, and although efforts were made to capture these studies, it simply was not possible to conduct an exhaustive synthesis of that body of work. This represents a major challenge for Africa-wide assessments.

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