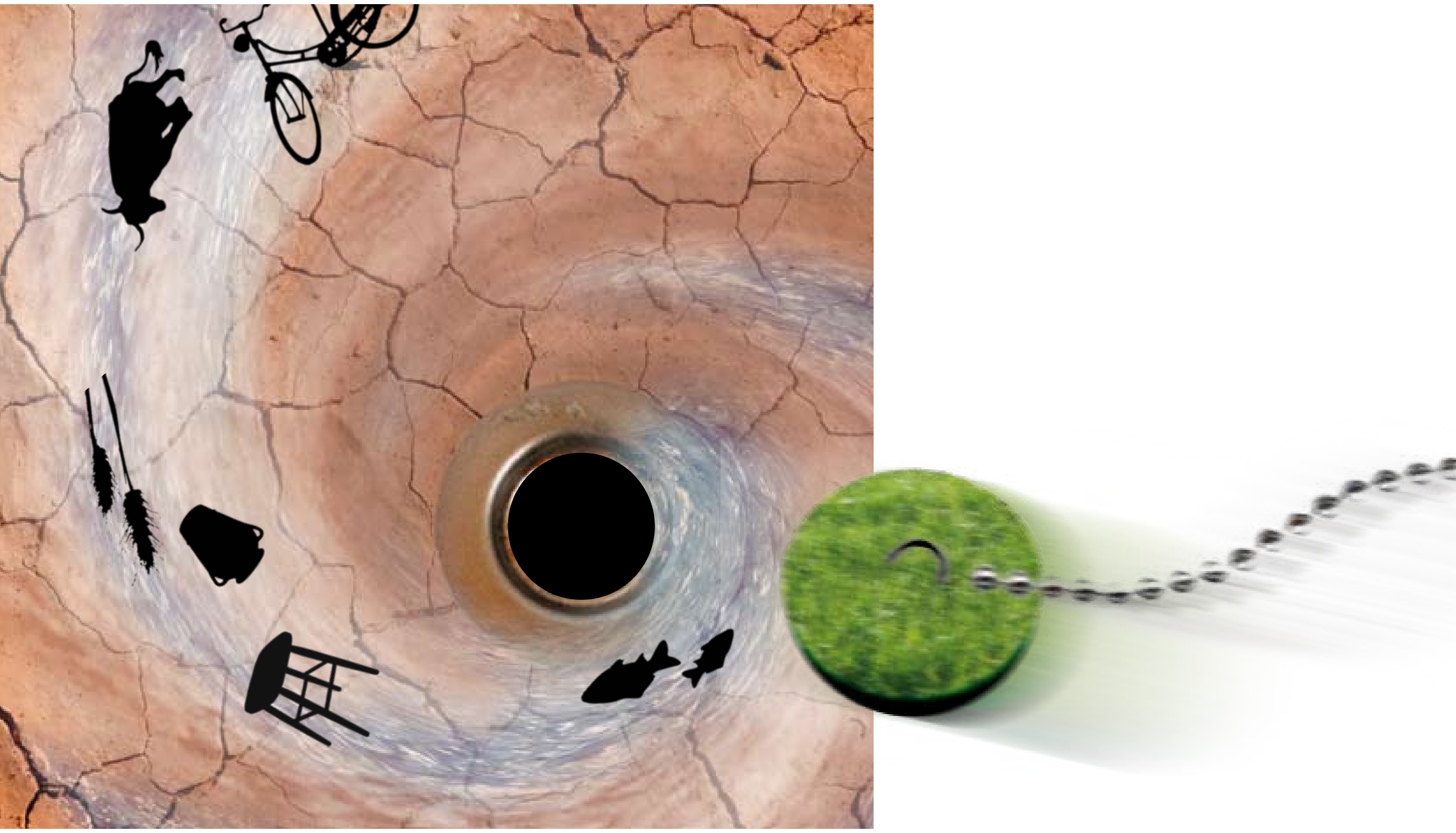

Water and Adaptation to Climate Change

Consequences for developing countries

gtz

On behalf of
Federal Ministry
for Economic Cooperation
and Development

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Mark Svendsen, Nana Künkel

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Preface

Global warming is confronting developing countries across the globe with enormous challenges not of their own making. The impacts of a warming world are now threatening to set back progress in improving the quality of life for billions of people. Water resources are likely to be impacted early and strongly in many countries; developing countries, however, are the most vulnerable.

German Development Cooperation has been supporting the water sector in developing countries for decades. This work is the foundation for future efforts to support adaptation, but needs to be revisited to make efficient and effective contributions to the adaptation challenge. The range of possible adaptation actions is wide, and clear understanding of climate change impacts and priorities for action will be needed in each country and region.

This publication demonstrates the strong and diverse hydrological impacts of climate change and vulnerabilities of development countries, for example for the up to 250 million people being exposed to increased water stress in Africa as early as 2020. It takes stock of where we stand in addressing hydrological impacts of climate change in developed and in developing countries. We are still at the beginning, but experience is growing rapidly. Finally it discusses the role of development cooperation. It highlights that international cooperation can assist countries in making needed adjustments, but can only be effective if adaptation efforts are integrated into overall national planning, existing strategies in water resources management and into capacity development.

The international community is challenged to provide assistance quickly and scale up its support significantly. Development cooperation will be an important partner due to its experience in the sector. The German Federal Ministry for Economic Cooperation and Development is committed to meet this challenge.

Dr. Manfred Konukiewitz,

Commissioner for Climate Policy
German Federal Ministry for Economic Cooperation and Development

Executive Summary

Developing countries, as a group, are the ones most threatened by the hydrological impacts of global warming, even though they are not its primary cause. Impacts are felt through the two principal mechanisms of higher temperatures and altered precipitation patterns. These two effects combine to produce melting mountain glaciers and snowpacks, altered flow patterns in streams and rivers, higher evaporation rates, more extreme precipitation patterns, and rising sea levels, among other things. Human populations will feel these effects in differing ways in different regions. Although some effects will be positive, at least in the short term, the primary impacts in most developing countries will be negative; harming livelihood activities (including crop agriculture, livestock raising, and fishing); reducing domestic water supplies; subjecting larger numbers of people to riverine and coastal flooding and landslides; and altering ecosystem habitats.

Vulnerability to climate change impacts is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. While efforts to mitigate climate change can reduce exposure, a society's adaptive capacity is critical in determining how seriously people will be affected by the changes in climate that will inevitably occur. Adaptive capacity is a complex function of a society's physical, human, and institutional resources, its infrastructure, its wealth, the structure of its economy, and other factors. Strengthening this capacity is the key to successful adaptation.

Much of the effort invested so far in adaptation to climate change in higher income countries has been aimed at improving the knowledge base as a prelude to action. This has involved developing modeling capacity, building databases and documenting baseline conditions, monitoring conditions and changes through reporting requirements on public agencies and water utilities, and analyzing potential impacts. Other efforts have been aimed at reducing demand for water and water consumption, and at inter-sectoral transactions designed to firm up urban water supplies in lean years and reallocate scarce supplies during droughts. Key lessons include the importance of integrating adaptation to climate change into routine government planning and management practices, and of starting early to develop the capacity and knowledge base needed to support subsequent actions.

The process of adaptation will involve a mix of private and public actors. Ultimately, adaptive actions will be the result of a multitude of individual decisions made by farmers, businesspeople and consumers. It is the task of government to supply the collective goods (such as knowledge and infrastructure) needed for effective adaptation, and to create incentives to guide and shape individual decisions into an appropriate collective response. Responsibility for coordinating adaptation actions should generally rest with a ministry or department with a broad mandate, such planning or finance ministries.

Setting priorities for action involves assessing exposure to threats, determining sensitivity to a changing climate, and assessing the national capacity to adapt. Key indicative priorities for initial action include addressing current and expected water scarcity problems, expanding the knowledge base on water resources and climate change exposure and impacts, and strengthening the national capacity for integrated water resource planning.

Areas for early adaptive action in the water sector in developing countries include:

- Integrating climate change into planning.
- Expanding the water resource knowledge base.
- Promoting use of water-saving technology and efficient water usage.
- Reforming management and governance practices.
- Augmenting water supplies.
- Investing in multiple use water systems.
- Supporting adaptive agricultural research.
- Developing insurance schemes for agriculturalists.
- Raising awareness among policy makers, opinion leaders, and the general public.

International development cooperation has an important role to play in building up adaptive capacity in the following areas:

- Policy analysis and change.
- Infrastructure development and technology.
- Changes in management and governance.

Development cooperation can contribute to improving adaptive capacity in these areas through provision of expertise in the area of climate and climate impact data, building up analytical and monitoring capacities, moderating and supporting processes of strategy development, reforms and institutional coordination or regional cooperation. There are important roles of financial cooperation in funding and designing water-related infrastructure, but also non-structural measures.

Adaptation in water resources is increasingly being adressed and appropriate forms of development cooperation will change over time as threats mature and adaptive capacity increases. Waiting until evidence of the damage and hardship resulting from climate change accumulates would be a serious mistake. Early preparation to face forthcoming changes is crucial.

Introduction

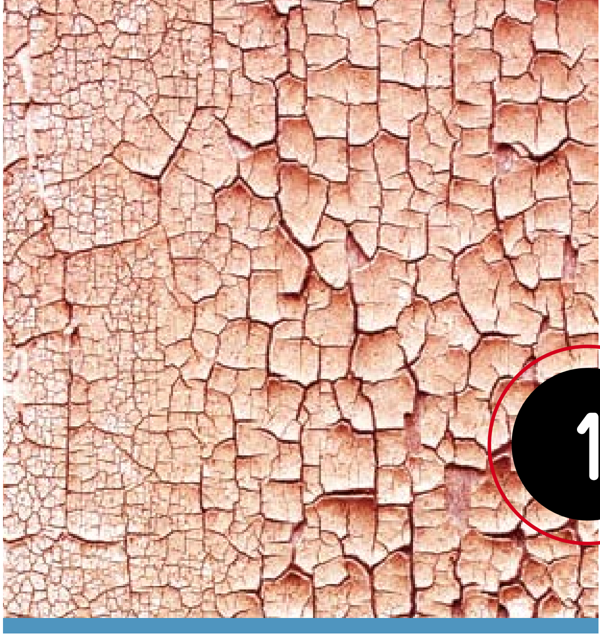
Developing countries, as a group, are the ones most threatened by the hydrological impacts of global climate change (GCC). This is true both because many of the poorest countries lie in those regions where GCC-related effects will be most damaging, and because their ability to respond to harmful change is the most limited. The objective of this study is to provide an overview of likely water-related climate change impacts in developing countries, to develop a framework for adapting to these impacts and to outline a strategy for international cooperation for corresponding adaptive efforts.

The study intends to provide a broad overview of the topic, describe its key dimensions, suggest promising interventions for further exploration, and serve as a basis for discussion. Its focus is on the impact that climate change will have on developing countries through its effects on surface and ground water hydrology. While agriculture is pivotal here, as it accounts for the lion's share of water consumption in most of these countries, the scope of this review also includes other water-related dimensions, such as flooding, drinking water, and ecosystems.

It is difficult to specify a time frame for the study. Even if carbon dioxide (CO_2) levels in the atmosphere were to cease rising tomorrow, the impact of past CO_2 releases on temperature and precipitation would continue for decades. Moreover, the further out into the future one plans the greater the uncertainty. This is largely because the future trajectory of increases in greenhouse gas (GHG) concentrations will depend to a great extent on the actions that humankind takes to reduce them. Our capacity and resolve on this score are unknown. Consequently, the study will generally emphasize changes expected by 2020 and 2050, which would be well within a human lifetime.

Complicating the task is the fact that life does not stop while the climate changes. Rather climate change is superimposed on a dynamic of population growth, rising incomes, globalization of the marketplace, and scientific progress. Moreover, attempts by developing countries to adapt to climate change run parallel to their ongoing efforts to develop economically. These two efforts must be integrated, as must international assistance efforts aimed in each direction.

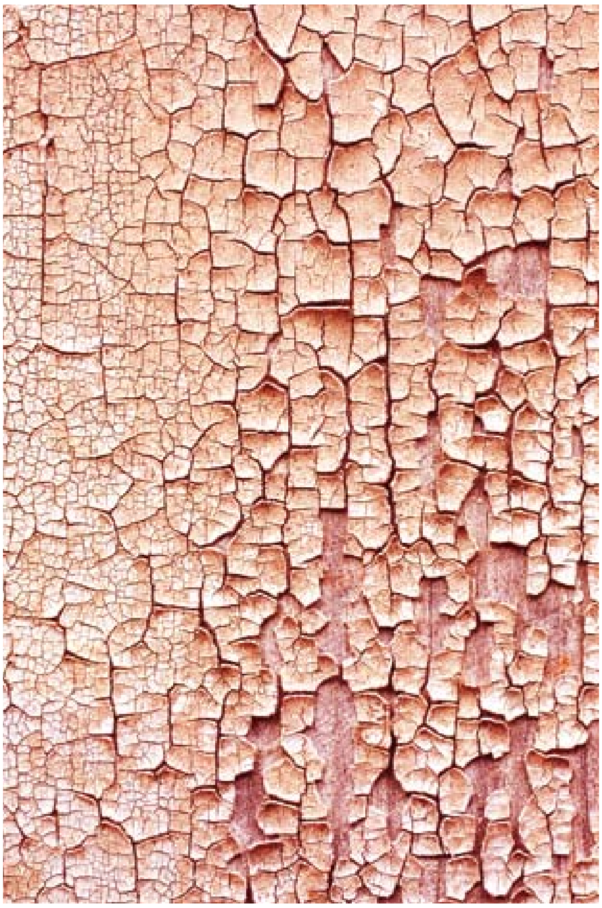
The study will not try to describe the mechanics of global warming, climate dynamics, climate modeling techniques, or other technical aspects of this very complex and interlinked set of phenomena. The Intergovernmental Panel on Climate Change (IPCC) has devoted thousands of pages to these issues. It will summarize predictions briefly, and identify the primary ways through which climate change is affecting hydrology. It will then develop a concept of "vulnerability" with respect to these hydrological changes and describe possible responses. Finally, it will describe possible roles for development cooperation in supporting adaptive action in vulnerable countries.



1

Global Warming and Climate Change

In 1896 Svante Arrhenius[1] made a remarkable prediction, warning that if coal burning were to double the concentration of CO_2 in the atmosphere, the temperature of the earth could rise by "several degrees". Three-quarters of a century later J. S. Sawyer of the U.K. Meteorological Office offered an equally prescient but much more detailed prediction about man-made carbon dioxide and the "greenhouse effect". After summarizing what was known about this type of CO_2 in terms of enhancing the Earth's natural greenhouse effect, Sawyer predicted that the CO_2 increase of 25 percent then expected by the end of 20th century would correspond to a 0.6°C rise in world temperature. In fact, the temperature rose by almost exactly this amount, namely by about 0.5°C.



Since 1988, the IPCC has consolidated the work of literally thousands of scientists to widen our understanding of this CO_2 -induced warming effect, and established a remarkable consensus among climate scientists about the effect and its implications. Nevertheless, despite the improvements in understanding resulting from this work, the global warming expected to result from a 25 percent increase in CO_2 remains at the same 0.6°C level predicted by Sawyer in 1972.

Predictions of future changes in temperature, precipitation, and CO_2 levels themselves vary according to the model used and the particular scenario favored from a range depicting alternative futures and hypothesized human actions for controlling the release of greenhouse gasses. Temperature predictions from an ensemble of models show increases of between 1.8 to 2.8°C by the end of the 21st century for scenarios[2] A1B and B1 relative to the

[1] Swedish scientist who was later awarded a Nobel Prize in chemistry.

[2] The IPCC developed scenarios in a Special Report on Emissions Scenarios (SRES) in 2000. The SRES scenarios are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways, The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy.

1980 to 1999 average (IPCC 2007a). Because this is a global average and because ocean temperatures tend to lag, temperature increases over land will be larger than this amount. This temperature rise will likely come on top of the anthropogenic increase of about 0.5°C that has already been measured for the period between 1900 and 1990 (Hansen, et al 2006).

Precipitation predictions indicate that global mean precipitation will increase because of the higher moisture holding capacity of a warmer atmosphere and higher evaporation rates from warmer water bodies. However, regional effects will differ. Models generally show increases in annual precipitation at higher latitudes and in the tropics, and decreases in the sub-tropics. Precipitation variability will increase across all regions (IPCC 2007a).

Another direct effect is that concerning CO_2 itself. In addition to its insulating effect on the planet, higher CO_2 concentrations in the atmosphere will tend to reduce the rate at which plants use water, namely their transpiration rate. This effect would offset, to some extent, increased plant transpirative demand caused by higher temperatures. However, it would not moderate evaporation from open water surfaces.

2

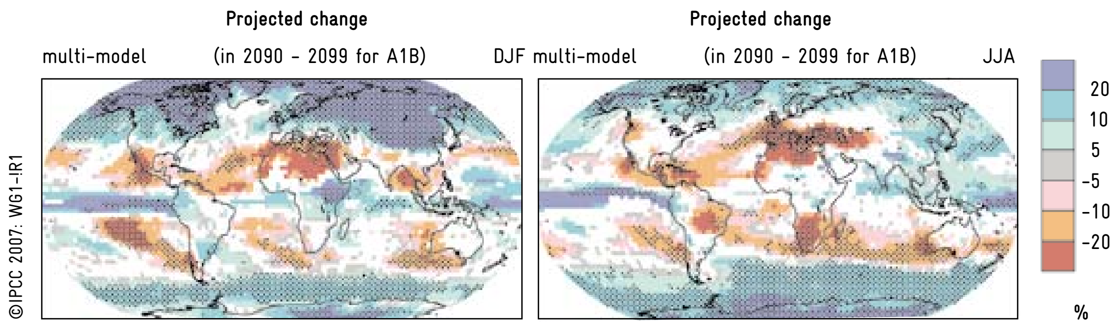
Hydrological Impacts of Climate Change

These basic changes in climate have various effects on the hydrologic cycle, which are interrelated and thus require hydrologic modeling to combine their interactions and impacts. Nonetheless, some of these effects can be identified under their drivers.

2.1 Temperature

One of the earliest and most powerful impacts of rising temperature is the melting of snowpacks and mountain glaciers which store precipitation as snow and ice in the winter for release during summer months. More than one-sixth of the world's population depends on these glaciers and snowpacks for its water supply. This includes people living in river basins fed by the Himalayas, the Sierra Nevada and Rockies in North America, the European Alps, the Snowy Mountains in Australia, and the Andes.

Another powerful and inexorable impact is the rise in sea levels. Sea levels rise because of two warming-related factors. The first is the thermal expansion of seawater as it warms. The second is the increase in the mass of water in the world's oceans resulting from melting of continental glaciers. Model ensembles predict central values of a sea level rise of between 0.28 and 0.35 meters by the end of this century for the two (i.e. A1B and B1) scenarios



White areas are where less than 66 % of the models agree on the sign of change and stippled areas are where more than 90% of the models are in agreement.

Figure 1

Multi-model patterns of precipitation changes projected in winter and summer 2090-2099 relative to 1980-1999.

mentioned earlier[3]. This rise will lead to inundation of low-lying lands and habitations and increased storm surge damage, with a particularly acute impact on deltaic countries like Bangladesh. It will also: increase salinization of coastal agricultural lands due to periodic flooding; alter natural habitat in coastal zones; destroy infrastructure such as roads, railroads, ports, and water treatment plants in low-lying coastal regions; increase tidal incursions into coastal rivers; and exacerbate saline water intrusion into coastal aquifers.

Higher temperatures will increase the rate at which water evaporates from oceans, lakes and reservoirs and from the soil surface. This will put more water into the atmosphere, but reduce supplies in storage reservoirs and cause soil to dry more quickly after rainfall or irrigation. Transpiration of water from forests, crops, and other plants will tend to increase as a result of higher temperatures and possibly higher wind speeds, but any increases will be offset, to some extent, by the inhibiting effect of higher atmospheric CO_2 concentrations.

Higher water temperatures will also have an effect on water quality by promoting growth of algae and microbes, and will affect the entire ecology of streams and water bodies. Effects here would include the impact on fish species caught for human consumption and those protected under various environmental regulations.

2.2 Precipitation

In regions not dominated by snowpack storage, changes in precipitation patterns are the most important determinant of changes in hydrology resulting from climate change. These changes have a number of dimensions, including the average annual amount of precipitation received, temporal distribution of the precipitation over the year, distribution of the intensity of precipitation events over time, the average interval between precipitation events and the apportionment of precipitation between rainfall and snow.

Despite their importance, however, changes in precipitation resulting from global warming are likely to be far

[3] The overall range of predicted values from the Fourth Assessment Report is 0.18 to 0.59 meters. Values are conservative in that they exclude future rapid dynamical changes in ice flow.

more variable spatially than changes in temperature and, at the same time, more difficult to predict. Figure 1 shows some projected changes and indicates where predictions are relatively solid across models.

Climate change impacts on annual and decadal weather cycles may also be significant but are not yet well-specified. Examples include the southwest monsoon that waters the South and Southeast Asia, and the El Niño Southern-Oscillation (ENSO) which affects weather in many parts of the globe, including Sub-Saharan Africa.

Higher intensity of precipitation events will lead to increased erosion and reservoir sedimentation, as well as more frequent and larger floods. Increased landslides in steep terrain will also be likely.

2.3 Combined effects

Rivers are the primary source of water for billions of people for irrigating crops and for domestic use. The pattern of flow in rivers, their hydrographs, are complex functions of many factors, including precipitation patterns, timing of snow melt, base flow from groundwater aquifers, and evapotranspiration from natural vegetation; all of which are potentially affected by climate change. Annual runoff is a primary driver of river discharge hence projected changes in runoff from a global study conducted by the U. S. Geological Survey are shown in Figure 2. Changes in precipitation generally result in magnified changes in surface runoff and river discharge (de Wit and Stankiewicz, 2006).

Another important function of precipitation is to recharge groundwater aquifers. Changes in the share of precipitation that infiltrates into the ground to recharge aquifers are strongly related to changes in the amount of precipitation, and to the timing and intensity of its occurrence. Groundwater recharge impacts are very site-specific, but where precipitation levels decline, groundwater recharge generally decreases more than proportionately.

Changes in water use by agricultural crops and native vegetation are a function of temperature, wind, and CO_2 concentrations, as well as the amount of water available to plants in soil. The combined effect of these factors is site-specific. However, because some of the effects concerned offset each other, the impact of climate change on plant

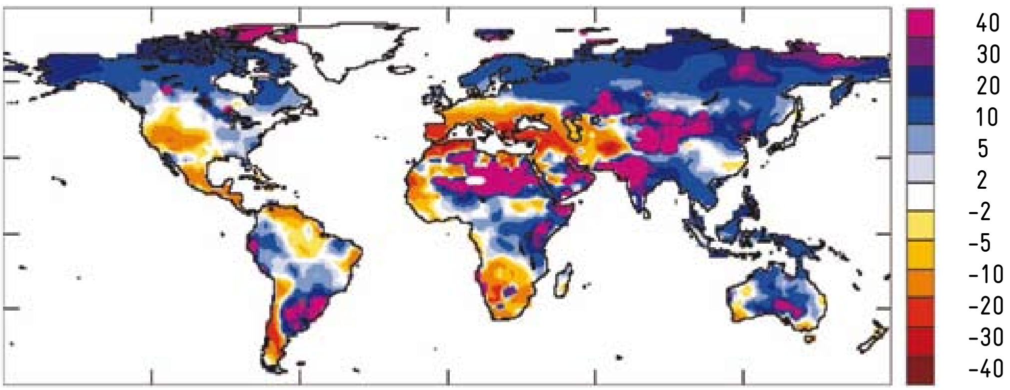


Figure 2

Percentage mean change in annual runoff by 2050 under the SRES A1B emissions scenario: based on an ensemble of 12 climate models (Milly et al., 2005).

water use will generally be smaller than its likely impact on the availability of water.

2.4 Human and environmental impacts

The changes in hydrology resulting from global warming and consequent climate change have profound implications for human well-being. Among the most important of these, because of the large volumes of water involved, is supporting sources of human livelihood. Water-dependent livelihoods include rainfed and irrigated crop agriculture, livestock raising, and fishing, while many other income-generating activities are indirectly affected.

2.4.1 Agriculture

Cline (2007) recently completed a study of the impacts of global warming on agriculture worldwide. The study applies averaged estimates of temperature and precipitation from a set of 6 climate models for the period 2070-2099 to suites of two different types of economic and crop models to make the predictions. Assuming a business as usual scenario with respect to GHG emissions, he concludes that reductions of global agricultural capacity of 10 to 25 percent could reasonably be expected by the 2080s, and that damages will be disproportionately concentrated in developing countries. Losses would be most severe in Africa and Latin America.

Lobell et al (2008) used probabilistic techniques to assess the likely impact of climate change predicted by 20 general circulation models on yields of crops important to the world's hungry in 2030. Median projections of average temperature increase produced by the models were roughly 1 degree C in most regions, while precipitation estimates varied widely. One resulting conclusion was that there were almost certain to be reductions in the production of highly hunger-important crops of South Asian wheat, Southeast Asian rice, and Southern Africa maize (95 percent probability) in the absence of adaptation measures. The largest predicted declines in hunger-important crops (5% probability) occurred in South Asian millet, groundnut, and rapeseed; Sahelian sorghum; and Southern African maize. The study highlights the importance of uncertainty in setting adaptation priorities and points out that while degree of uncertainty varies widely among region and crop combinations, for some of these combinations its inverse, certainty, can be fairly high with respect to the direction and magnitude of likely crop impacts.

2.4.2 Irrigation and Drainage

Climate change holds profound implications for irrigation and drainage across the world. Some of the earliest impacts to be felt and the best defined impacts relate to the loss of snowpack and glacier storage for winter precipitation. Measurable reductions in snowpacks and shifts in spring runoff hydrographs are already evident in the Western United States and Australia (Barnett, et al., 2008), and are likely occurring in India, Pakistan, China and elsewhere too. This may induce a corresponding shift in planting calendars as farmers try to avoid late season droughts, when snowmelt used to provide a reliable water supply, by planting earlier. Higher spring temperatures may facilitate a move to earlier planting dates, but the interaction between changes in seasonal temperature and runoff profiles need to be assessed on a case by case basis.

Climate change holds several other negative effects on water storage. First, higher temperatures will increase evaporation losses from lakes and reservoirs. Second, more intense precipitation events will lead to greater watershed erosion and consequent reservoir sedimentation. The increased likelihood of more intense storms may also require maintaining more flood storage capacity in reservoirs or even redesigning emergency spillways. In any event, system design techniques must be updated to accommodate non-stationary precipitation distributions (Milly, et al., 2008). Water stored as fresh groundwater in coastal aquifers can also be contaminated by saline water intrusion in response to higher sea levels (Ohio State University, 2007).

On balance, water supply impacts are likely to be more pronounced and have greater impact on irrigated crop production than increases in transpiration. Reducing demand through more efficient irrigation technology has significant potential to help farmers deal with reduced supplies. Drip irrigation technology can be applied at a wide range of scales and is an important adaptation practice in virtually every continent and country.

With respect to drainage, the strongest impact is likely to be the need for increased surface drainage, particularly in lowland delta regions. Higher intensity storms and earlier spring runoff in snow-fed rivers will lead to increased flooding. In addition to their primary impact on lives, crops, livestock, and property, floods bring the threat of epidemics in their aftermath. Increased surface drainage capacity may be required to prevent crop damage or loss. Another option is use of new seed varieties more tolerant of submergence, such as the "waterproof rice" developed by the International Rice Research Institute which can endure up to two weeks of submergence (CGIAR, n.d.). Human encroachment into flood plains and the absence of flood response plans increase the damage potential and may need to be addressed.

Drinking Water in South America

Water supply in Quito, Ecuador, comes in part from meltwater runoff from Andean glaciers. With these glaciers diminishing at an unprecedented rate, the city is planning, under its Western Waters scheme, to construct a $1.1 billion tunnel through the cordillera to tap Amazon basin runoff.

In Bogota, Colombia, 70 percent of the city water supply comes from alpine paramo (a fragile sponge of soil and vegetation), which could dry up under higher temperatures.

An estimated 40 percent of the piped supply in each city is lost to leakage and theft.

Source: Canadian Press

2.4.3 Other impacts

Some semi-arid and sub-humid regions of the globe such as the Sahel are already suffering from more intense and multiannual droughts, highlighting the vulnerability of these regions to the increased drought occurrence that is expected in the future due to climate change (IPCC, 2007b). Droughts have a direct negative affect on rain-fed agricultural production, including livestock production, in addition to their impact on water supplies for domestic, industrial, and irrigation purposes.

Availability of water for drinking and sanitation is another critical issue, affecting both those in urban areas, and rural residents dependent on wells, springs, and streams. Both water availability and water quality will be threatened in many locations. The impact on women is especially concerning, since women usually bear primary responsibility for carrying water to the home, and are often the primary cultivators, particularly in Africa.

In drying environments, the risk of wildfires will increase, affecting livestock grazing, timber-based livelihoods, and watersheds supplying drinking water to urban areas, in addition to their direct threat to human lives and structures. Burned over watersheds in hilly areas are also at greater risk of catastrophic landslides, particularly in response to expected higher intensity rainfall events.

Changes in timing and amount of runoff will also bring potential conflicts among water uses - for example in operating reservoirs for power production, irrigation, and flood protection under altered inflow patterns.

Natural ecosystems have evolved to exist in environmental niches with particular hydrological characteristics. Many ecosystems are already stressed by changes in land use, diversion of water from rivers, and widespread release of industrial contaminants. Alternations in temperature and hydrologic regimes resulting from global warming will add to these stresses and will likely lead to additional loss or displacement of habitat, loss of biodiversity, species extinctions, and increased desertification.

3

Vulnerability and Adaptation to Impacts

The immediate impacts of climate change pose a threat to a large share of the world population, not so much for the higher or lower levels of temperature and rainfall that they yield, but rather for the fact that global warming is altering these levels drastically and rapidly. In past eras of dramatic climate change, human populations simply migrated to a more favored climate. Today, human populations are no longer nomadic, and where groups of people still do migrate, adjacent lands are often settled and unavailable for extensive in-migration. Moreover, economic progress is based, in part, on the accumulation of capital in the form of physical infrastructure, namely our cities, harbors, airports, roads, railroads, factories, and farms. Our economic system is tethered to this infrastructure. Had societies developed under different conditions, say those now expected in 2100, we may well have been no worse off than we are today. However, we would have evolved vastly different settlement patterns and situated our economic activities differently. Adapting to sharply altered climatic conditions thus involves massive investments to adapt or relocate infrastructure, as well as towards providing for basic human needs and livelihoods[4]. Uncertainty about the exact pattern of these climate changes makes the adaptation task doubly difficult.

The scientific literature, as consolidated by the IPCC, demonstrates that the ongoing changes in climate will have a wide range of impacts on human populations that will vary in nature and intensity across the world. It has been said that while warming is global, climate change is local.

Although climate change will have impacts that can be positive for some areas and groups of people, the most significant impacts are expected to be negative. Positive impacts for agriculture, in the form of increased rainfall and longer growing seasons, will mostly be experienced in the northern hemisphere, particularly the higher latitudes of North America and Eurasia. Areas where lower precipitation plus elevated temperatures will cause negative changes in water availability, in general, and harmful affects on agriculture, in particular, include the Mediterranean region, Southern Africa, the Western United States and Northern Mexico, and Brazil (Figure 1).

Moreover, some groups within these regions will be more strongly affected than others. In order to design adaptive strategies, it is necessary to assess the regions, systems, and population groups which are most vulnerable to the impact of climate change.

Unfortunately, there is no single universally accepted definition of "vulnerability". Several recent reviews of the literature describe various approaches to vulnerability and adaptive capacity (Deressa, forthcoming; Smit and Wandel, 2006; Nhemachena, et al., 2006). A general definition that has emerged from the climate change literature is the one articulated by the IPCC, as shown in

[4] The Stern Review (Stern, 2006) has estimated these costs, along with the costs of mitigation, showing that early mitigation is distinctly less costly than the economic loss which would otherwise result.

the previous box. This concept of vulnerability underlies a framework that links human welfare to climate through the key concepts of "exposure," "sensitivity" and "adaptive capacity."

Deressa (forthcoming) presents several models linking these concepts into frameworks. An adaptation of one of these frameworks is shown in Figure 3. Important terms in the adaptation section of the model are defined briefly below.

Exposure is the nature and extent of the changes in climate that a region experiences or will experience. It is expressed in the form of outputs of global circulation models (GCMs) and, increasingly, as results of analyses of past climatic records showing longer-term changes arising from global warming. GCM outputs must generally be scaled down, using more refined regional models to yield regionally-useful results. Nonetheless, there is still substantial uncertainty in predictions obtained, stemming both the uncertainty inherent in such models themselves and from the uncertain trajectory of future GHG emissions resulting from our actions.

The **sensitivity** of a system to changes in climate specifies how its key natural resource-related units respond to exposure to climate change. Responses, of course, will differ from region to region and from ecosystem to ecosystem. As precipitation decreases, for example, things like river flows, groundwater recharge, populations of native plants and animals, and agricultural crops will change in linked ways. A huge variety of factors influence system sensitivity. As regards river discharge, for example, factors here include the: degree to which snowmelt is a water source; share of groundwater contribution to river flow[5]; evaporation rate for open water surfaces; and the response of native vegetation extracting water from river margins etc. Modeling is usually needed for a comprehensive understanding of interrelated causes and effects.

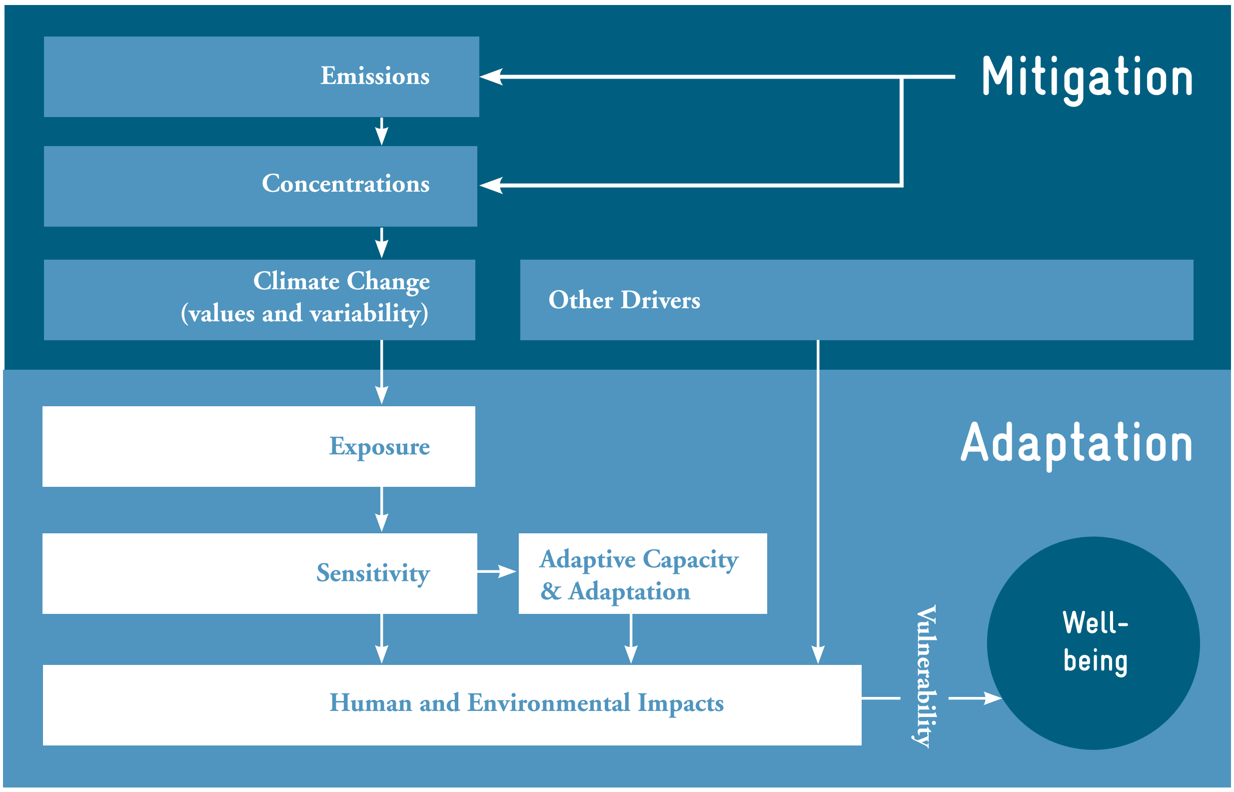


Figure 3

Climate change adaptation and impact model

Adaptation is the key to a society's ability to deal with climate change. It comprises the sum of actions taken to change behavior, shift priorities, produce necessary goods and services, and to plan and respond in those ways that reduce harmful climate change impacts or transform them into positive opportunities. Adaptation can be anticipatory or reflexive, come from the public or the private sector, and be short- or long-term in perspective.

Adaptive capacity is the ability to adapt. It is a function of a society's stock of infrastructure, its human resources, its technology base, its educational system, its research capacity, its wealth, its natural resource base, the structure of its economy, and many other factors. This is a key intervention point in the vulnerability paradigm[6].

The term "adaptation" has its origins in the field of evolutionary biology, where it refers to the development of characteristics which enable organisms or systems to cope with environmental changes in order to survive and reproduce (Smit and Wandel, 2006). With respect to climate change, adaptations are adjustments or interventions which take place to manage the losses or take advantage of the opportunities presented by a changing climate. Adaptive capacity is the ability of a system to adjust to climate change in order to moderate potential damage, to take advantage of opportunities, or to cope with corresponding consequences (IPCC, 2001).

Responses of natural systems to climate change, modified and buffered by the adaptive actions undertaken by societies and individuals, result in the **human and environmental impacts** of climate change. Types of expected human impacts were outlined briefly in the preceding section. If a society were capable of adjusting perfectly to cope with all of the harmful human impacts which would otherwise result from exposure to climate change, then vulnerability would be nil and population well-being would be unaffected. **Vulnerability**, in this framework, comprises the residual effects on human well-being after a society has employed its adaptive capacity to moderate harmful changes. Overall, this model has two important aspects that distinguish it from more traditional "vulnerability" frameworks. First, it considers more aggregate levels of society, up to and including the national level, in addition to individual households. Traditional vulnerability models are centered on the household and focus largely on response capacity and decision making at this level. The focus here emphasizes larger-scale public actions as a complement to those individual ones taken at the household level.

Second, the model focuses on adaptation rather than on vulnerability. It thus places greater importance on those points that can be altered to help adapt to harmful climatic change than it does on the characteristics of individual households that may constrain their ability to adapt. That is not to say that household level strengths and weaknesses are unimportant, but simply to acknowledge that the magnitude and scope of expected climatic change impacts will often require larger-scale intervention that is well beyond the capability of individual households. A concept of "vulnerability" is still present in the adaptation and impact model, but it plays a more modest role as the "residual" that affects population well-being after adaptive actions have been undertaken. This focus on adaptation leads to a more pro-active stance than the more passive vulnerability approach.

Vulnerability is the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

IPCC, 2007c

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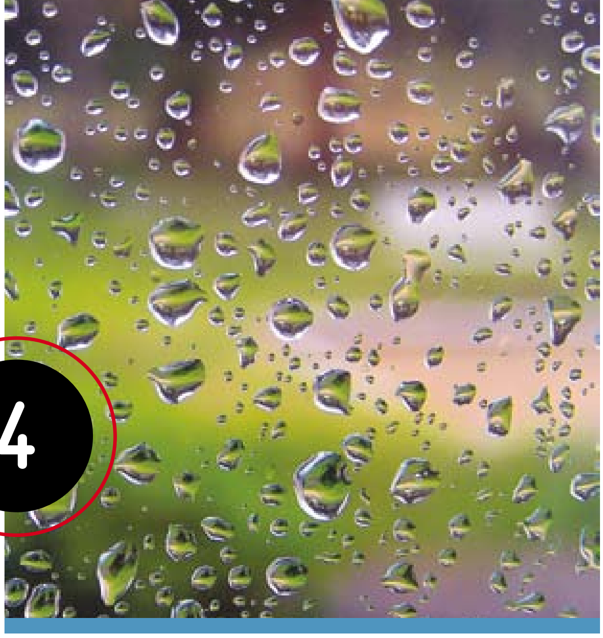
5 This also responds to changes in precipitation.

6 Ironically, energy is critical to overcoming many water-related GCC impacts. Processes such as those involving desalinization of seawater or brackish water, pumping of groundwater, or lifting of water from surface sources where it is not accessible by gravity flow are all of an energy intensive nature. They represent a positive feedback loop to global warming unless de-carbonized energy sources are tapped to power them.



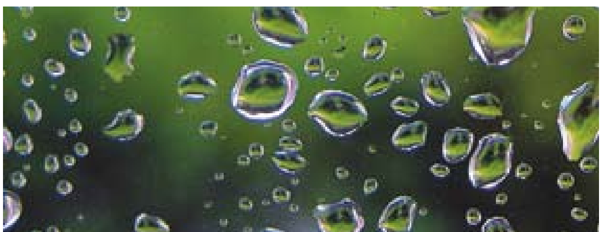
4

Responses to Impacts

Two types of responses to global warming must be made. Mitigation responses are those that are designed to curb the release of GHGs into the atmosphere. Adaptation responses, on the other hand, encompass efforts to offset negative economic impacts and to temper economic and social risk and hardship.

4.1 Responses

Most public attention to date has focused on mitigation, which is urgent and essential to arresting human-induced warming of the terrestrial system. Increasingly, however, planners and policy makers are also recognizing the need to prepare for the inevitable impact of changes already set in motion. Examples here would include: relocating settlements situated on flood plains of increasingly flood-prone rivers; extending transportation infrastructure to serve newly-enabled agricultural areas (as in southern Canada); and drilling wells in rainfed agricultural areas to compensate for reduced rainfall. Examples of responses from California and the European Union are presented below.



4.1.1 California

In California, climate change is already having an impact on the state's water supply, which depends greatly on annually accumulated snowpack in the Sierra Nevada mountains along the state's eastern boundary. However, this effect is underpinned by other non-climate drivers which are also putting pressure on supply. These include: rapid population growth, especially in arid Southern California; a recent reduction in the state's effective allocation of Colorado River water, which comes into the state through an inter-basin transfer; and court-ordered reallocations of water to sustain endangered fish populations. In the recent past, non-climate drivers have probably been more important than the warming-related ones in reducing state water supply for human uses. However, the latter will become increasingly important in years to come (Figure 4).

California relies on snowpack for a major contribution to annual water storage. Computer modeling of global climate change scenarios predicts significant reductions in future snowpack. A 52 percent reduction in the annual April through July runoff is expected to arise from warming of 2.1°C (3.8 F) (Knowles and Cyan, 2001; cited in California Water Plan Update 2005).

The combined impact of these drivers has forced California to implement a number of innovative measures in response.

- **Household water conservation.** Los Angeles has grown by 1 million people since the 1970s but still uses the same amount of water. The Metropolitan Water District of Southern California (MWD) provides rebates to homes and businesses for installing water-saving appliances such

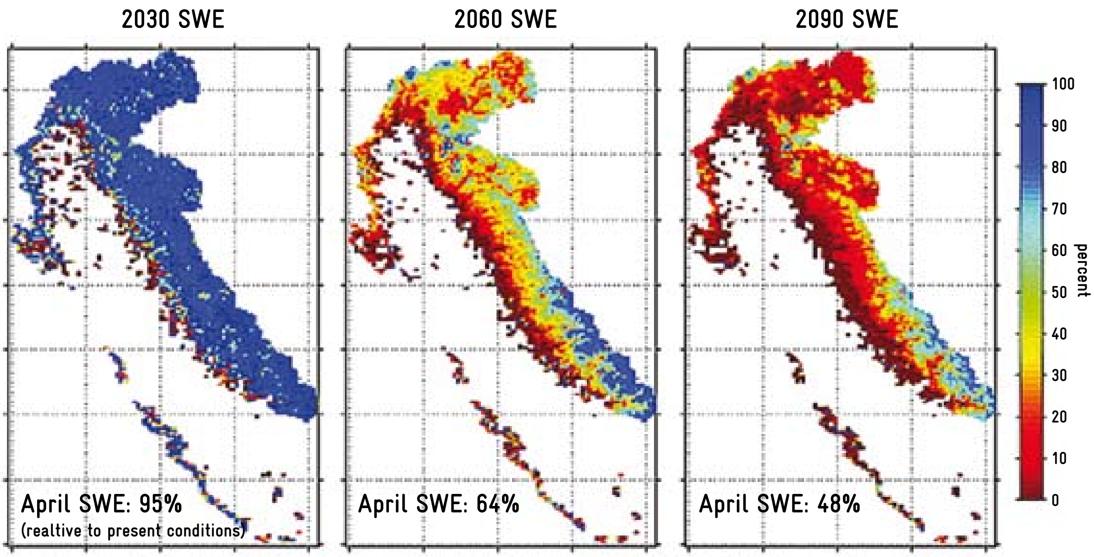


Figure 4

Model simulation of potential changes in snowpack during the 21st century

as high-efficiency clothes washers, low-volume toilets, and "smart" weather-based landscape irrigation controllers. It also works with developers of new homes to help them meet water-efficiency standards and gain certification as being "California Friendly". In 2005, the MWD issued about 300,000 rebates.

◗ **Agricultural water transfers to urban areas.** The MWD has had an aggressive program of paying for water-conserving technology in local irrigation districts in exchange for part of the water saved. This program involves lining conveyance and delivery channels, the pump-back of irrigation tailwater and other measures.

◗ **Water banking.** The MWD has undertaken agreements with a number of irrigation districts in southern California to promote underground storage of excess water in "good" water years. In years of poor water supply, the MWD can then request these districts to pump the water out again for it to distribute to businesses and households. This refillable groundwater reserve will soon have a capacity of around 1 billion cubic meters. At the end of 2006, the MWD had 344 million cubic meters of water stored underground in this way.

◗ **Water markets.** Between 1999 and 2002, 3.9 billion cubic meters of water entered the market in California for trading. They were traded in the form of annual leases of water use rights, as opposed to direct sales of water rights. Although they were not necessarily developed in response to climate change, all of these measures can be employed directly to respond to the water shortages and increased variability that are likely to result from climate change.

Recently, Governor Schwarzenegger proposed constructing two new dams in the state and the expansion of a third at a cost of around $9 billion. Significantly, two of the three dams provide off-line storage. This makes them useful for peak demand power production, as well as for storing water, and also reduces their impact on fish and other biota. Nevertheless, in environmentally-active California, this proposal has evoked a strong reaction from the environmental community. Still, it seems likely that additional storage, in some form, will be a part of California's future water plans in response to climate change.

In terms of planning and analysis, California has taken a number of steps to facilitate adaptation. In 2003, the California Energy Commission established the California Climate Change Center as a virtual institute that links climate change-related activities at the Scripps Institution of Oceanography and the University of California at Berkeley (see box). The Center carries out research on climate change detection, analysis, and modeling and also on economic and policy issues.The Center has produced an excellent layperson's guide to climate change in the state[7].

California Climate Change Center: Research Priorities

Monitor, analyze, and model the climate.

—

Analyze options to reduce greenhouse gas emissions.

—

Assess physical impacts and adaptation strategies.

—

Analyze the economic consequences of both climate change impacts and efforts to reduce emissions.

In 2005, the governor signed an executive order calling for the California Environmental Protection Agency to prepare biennial science reports on the potential impact of continued global warming on certain sectors of the California economy. To carry out this mandate with respect to water, the California Department of Water Resources cooperated with the U.S. Bureau of Reclamation, producing an excellent report on integrating climate change into the management of California's water resources[8]. The state is also incorporating climate change into its 25-year framework plan for all state water, namely the California Water Plan. The Water Plan was first published in 1957 and is updated every 5 years. The 2005 update was the first in which climate change was explicitly considered. The policy recommendations in this update call mostly for additional studies, though one adaptive response supported is for beginning to implement climate-related changes in the management of the State Water Project[9]. As pressure on the water supply mounts and as the volume of available science grows, more adaptive measures should follow.

4.1.2 European Union

The European Commission (EC) recently produced a green paper on adapting to climate change, which suggests the strategy to be followed here. It looks at actions to be taken within Europe, but also suggests ways for the EU to provide "international leadership" in adaptation. Although not focused on a particular sector, it uses numerous water-related examples, and water would seem to be an ideal sector in which to apply the principles articulated in this paper.

The paper outlines two types of measures which can be taken by the private sector. The first are "soft", relatively inexpensive ones, such as water conservation, changes in

7 http://www.energy.ca.gov/2006publications/CEC-500-2006-077/CEC-500-2006-077.PDF

8 http://baydeltaoffice.water.ca.gov/climatechange/DWRClimateChangeJuly06.pdf

9 The State Water Project is the backbone storage and conveyance system that brings water from northern California to Los Angeles and other cities and farms in the arid south of the state.

10 The second category of measures appears to include items which would require both public and private sector action.

agricultural practices and cultivars, planning, and awareness-raising. The second type is more costly "defense and relocation measures", which basically involve infrastructure (such as raising dykes, relocating ports, industries and population centers, and building new power plants[10]). Examples of public sector actions suggested include spatial planning, changes to building codes, updated disaster management strategies, and flood and wildfire warning systems. The green paper suggests that public sector action is needed at EU, national, regional, and local levels.

It further supports four lines of action at the EU level. These are: (1) early action in the EU by integrating adaptation into existing policy, laws, and funding mechanisms; (2) integrating adaptation into EU external actions; (3) expanding the knowledge base through research; and (4) involving civil society, business, and the public sector in preparing adaptation strategies. Items (1), (3), and (4) could also serve as priorities for developing country actions at a national level.

Item (2) indicates that adaptation will be essential in reaching Millennium Development Goals (MDG), particularly in sub-Saharan Africa. The means suggested include integrating adaptation into existing external policies and funding instruments, designing new policies, sharing EU adaptation experience, and integrating adaptation into poverty reduction strategies, while building on existing partnerships wherever possible. The paper suggests working with existing funding mechanisms, such as the Adaptation Fund under the Kyoto Protocol, the Global Environmental Facility, and bilateral programs. Nonetheless, it also indicates that the EC has earmarked 50 million over the period 2007-2010 to support dialogue and targeted mitigation and adaptation measures in developing countries.

4.1.3 Lessons

Much of the effort invested in adaptation to climate change in higher income countries has been aimed at improving the knowledge base as a prelude to action. This has involved developing modeling capacity, building databases and documenting baseline conditions, monitoring conditions and changes by placing reporting requirements on public agencies and water utilities, and analyzing potential impacts. Other efforts have been aimed at reducing water consumption and demand for water, and at inter-sectoral undertakings designed to firm up urban water supplies in lean years. Key lessons include the importance of integrating adaptation to climate change into routine government planning and management practices, and of starting early with developing the capacity and knowledge base required for supporting later adaptation actions.

4.2 Roles and responsibilities

Some of the adaptive responses which are already occurring result from individual actions by farmers, business people, home owners and water suppliers, acting independently in response to changing conditions. These would include: farmers' decisions on crops to be planted, pesticides used, and the timing of planting and harvesting; business peoples' decisions on factory locations based on expectations about future water availability; and home buyers' possible reluctance to buy houses in increasingly flood-threatened plains.

Other responses by individuals have been mandated by public agencies, for example through regulations requiring home builders to equip new homes with water-saving devices or restrictions on landscape watering. In the future, commercial concerns will play an increasingly important role in adaptation, as market opportunities related to climate change present themselves. Some of these will result from purely commercial opportunities, for example, when farmers increase their use of micro-irrigation equipment in response to reduced water supplies, raise agrochemical use due to expanded ranges of agricultural pests and diseases, or shift to carbon-sequestering low-tillage cultivation. Others will result from public mandates, such as ones requiring installation of low-flow showerheads or low volume toilets in new houses.

Other adaptive responses have resulted directly from government initiatives and have been carried out either directly by government agencies or by universities and other organizations under contract. In general, the role of public sector agencies includes: (a) providing public goods such as knowledge, forecasts, and infrastructure; (b) providing quasi-private goods and services, such as irrigation infrastructure or domestic water supply systems, particularly for those who can't afford to pay the full costs of such services; (c) providing livelihood assistance through retraining or job creation credits to workers displaced from agriculture; and (d) creating a framework of incentives and sanctions that will guide individual choices that impact adaptation. Within the public sector, allocation of responsibilities for action among public agencies is largely a function of the structure and political economy of those government units involved. For example, the California Climate Change Institute was established under the state's Energy Commission, rather than under the Department of Water Resources or the state Environmental Protection Agency, which may perhaps have been more logical choices. Prescriptive assignment of responsibilities in developing countries, based on nominal "ideal" structures, or structures established in other locations, is generally inappropriate. Factors that will come into play include nominal agency mandates, the relative power of different agencies, linkages between agencies, the prevailing institutional culture, skill set and disciplinary dominance within an agency, plus leadership capacity. The particular characteristics of each situation must be considered explicitly when selecting an appropriate structure for managing adaptation to climate change. Because of the pervasiveness of climate change impacts, a ministry or department with a broad mandate, such as planning or finance, would generally be an appropriate choice for coordinating adaptation interventions (Sperling, 2002).

Selected international organizations working in the water area are listed in Annex 2. These organizations play an important role in providing goods and services (such as knowledge development and dissemination, information exchange, and awareness-raising) that possess economies of scale or require an international footprint in order to be effective. They can also serve to build consensus on the need for action and provide legitimacy and support to reformers at the national level.

4.3 Application to developing country settings

Most developing countries have not yet started, or are only just beginning, to organize adaptation to changing climates. Efforts vary depending on the stakes involved, the capabilities of the government and the national scientific establishment, and the relative priorities of competing policy agenda items.

In Egypt, the Ministry of Water Resources and Irrigation (MWRI) has an ongoing program to model climate change impacts on Nile River inflows: an issue of enormous importance to the country. The program is operated by the Planning Sector of the ministry, with assistance from climate modeling specialists under a Dutch-aided support program. In addition to climate change impacts, the modeling work it conducts also assesses the potential impact of proposed dams on Nile tributaries in Sudan and Ethiopia on inflows to Lake Nasser. Preliminary results show that the impact of these dams would be far more significant than that of climate change itself in the short- to medium-run. This confirms the importance of integrating climate change assessment into the larger scope of water resources planning, rather than treating it as a stand alone exercise. It also has implications for institutional structure and the assignment of modeling responsibilities.

In addition, Egypt has established an Environment and Climate Research Institute as one of 12 institutes under the National Water Research Centre, for which MWRI is also responsible. The Institute is just gearing up to undertake work on climate issues. As yet, there is little other activity in water-related climate change assessment and climate change is not well integrated into national planning processes.

In India, the climate change stakes are high. The population of over 1 billion is heavily dependent for its food supply on both the southwest monsoon and on glacier-fed rivers rising in the Himalayas, and the population and infrastructure along 7,000 km of coastline is at risk from rising sea levels. India is also home to a large and capable scientific research establishment, and to the chairman of IPCC. Although admittedly getting a late start, India is pushing to establish a world-class climate change research capability. The Indian Institute of Technology in Delhi, the Indian Institute of Tropical Meteorology, The Energy and Resources Institute, and others have active programs of research in climate change.

The Government recently initiated a coordinated analysis of the impacts of climate change in a number of sectors across India. Seventy-five research institutions will carry out the studies based on projections of climate parameters prepared by the Institute of Tropical Meteorology. Some of the studies will focus on 14 river basins and include potential impacts on dams and irrigation systems (Times of India, 2008)

India is also developing an adaptation policy as spelled out in the National Action Plan on Climate Change which shall be implemented through eight missions representing multi-pronged, long-term and integrated strategies for achieving key goals in the context of climate change. Effective water resources management is one of the missions, as is safeguarding Himalayan glacier and mountain eco-systems.

Based on the aforementioned responses to climate change a number of conclusions emerge:

- Study and assessment of climate change implications are often the first steps undertaken. In developing countries, where this first involves capacity building, pairing arrangements with established research organizations are a common practice.
- Most countries, regardless of income level, are not yet at the stage of making large infrastructure investments solely to adapt to climate change impacts.
- Climate change issues are often integrated with or subsumed under more general issues of water supply and water scarcity. Sometimes climate change impacts are still invisible and unrecognized, but will benefit nonetheless from adaptation to general water scarcity problems.
- Countries are willing and capable of separating mitigation and adaptation responses to climate change. Thus, adaptation is relevant even to those countries that do not recognize a near-term responsibility to help mitigate this problem.
- Developed countries, in particular, often establish multi-agency frameworks to house and govern institutions working on climate change assessment and adaptation.
- There are basic differences between wealthier and less-wealthy countries as to the likely impact of climate change following adaptation. In particular, less-developed countries may face problems of hunger, epidemics, and mass migration that are unlikely in higher-income countries. Such potential problems would require special focus and support.

EC Research Priorities

Develop methodologies for impact and vulnerability assessment.

—

Improve assessments of potential climate change impacts.

—

Assess ecosystem impacts.

—

Improve models, datasets, and information systems.

—

Produce 4-5 yearly synthesis reports on climate impacts, adaptation and vulnerabilities.

—

Support research on adaptation for businesses and industries.

—

Assess plans and costs of adaptation in coastal regions

—

Assess flows, availability, and use of natural resources worldwide.

—

Promote cooperation and sharing within the scientific community, including developing countries

—

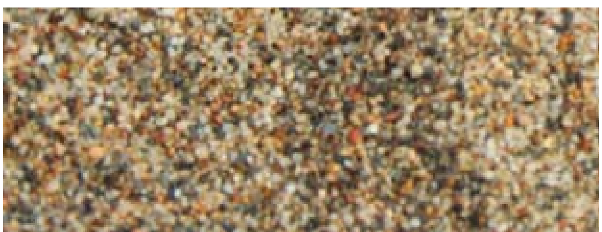
Facilitate transmission of knowledge from researchers to practitioners.

5

Adaptive Action in Developing Countries

Lower income countries have a particular problem in assessing and adapting to climate change in that they typically have a primary focus on economic and social development. Climate change is only one of a number of factors they must consider in pursuing this overarching goal. Moreover, climate change will often not result in separately-identifiable impacts, but will add to existing problems and trends. For example, overexploitation of groundwater as a result of population growth and agricultural intensification may be exacerbated by the reduced groundwater recharge arising from a changing climate. Distinguishing between the separate sources of a resulting impact may be difficult. Having said this, because adaptive actions will often be similar, this may not matter so much in practice.

Since adaptive actions will also have ecological effects that need to be considered these must also be included in the planning framework. An overarching theme for action is thus to integrate the expected hydrologic impacts of climate change solidly into existing national and sectoral planning processes.



5.1 Assessing priorities

The adaptation model presented earlier (Fig. 3) serves as a guide for developing adaptation priorities at a national level. Assessing **exposure** is the first step and draws on the outputs of global and downscaled regional models of predicted climate change impacts across a country. These impacts will be expressed in terms of expected patterns of temperature and rainfall (including both average levels and variability), frequency of extreme events, and sea level rise.

Assessing **sensitivity** is a two step process. The first step is to assess the likely impact of exposure to hydrology by using climate model outputs to drive hydrologic models that, in turn, predict future patterns of snowmelt, runoff, groundwater recharge, evapotranspiration, occurrence of floods, coastal inundation, seawater contamination of coastal aquifers, and so forth.

The second step is to examine the follow-on impacts of hydrologic changes on water-dependent human economic and social systems and important ecosystems. These would include agricultural production systems (including crop agriculture, animal husbandry, and pisciculture); domestic water supply; industrial water supply; and riverine, estuary, and coastal ecosystems. Changes in agricultural production of various kinds will have a huge impact on human welfare in many developing countries, either directly or through their economic linkages. Changes in domestic water supplies, likewise, can critically impact human welfare, regardless of whether water is supplied from an urban piped system or from boreholes, springs, or streams in rural areas.

Ecosystem impacts are important to humans from a variety of standpoints. First, aquatic ecosystems in developing countries are very often used as sources of food by fishers and hunters and as a source of medicines and other products. Additionally, they play an important role in coastal protection, improve water quality, buffer flood flows, and help regulate the climate. They also may support recreation and tourism and have a religious significance for certain groups[11], as well as an existence value (IIED, 2007).

Once sensitivity assessments have been made, it should be possible to highlight those areas where harmful impacts are expected to be particularly acute, and to envisage the type of adaptive action which could be taken. Specifying a particular set of priorities for action, though, depends on society's ability to implement necessary actions; in other words on its adaptive capacity.

Assessing **adaptive capacity** is perhaps the most difficult of the three assessments involved. While it is clear that the capacity to adapt is related to a number of factors, including national wealth, human resource capacity, the institutional base, government effectiveness, infrastructure, and the given resource base, there is no simple way to combine these factors into an assessment of a nation's ability to adapt to intense and widespread change. Practically, it may be easiest to identify a group of possible adaptive measures and then assess the capacity of a society to apply these specific measures, rather than to try to characterize adaptive capacity in an abstract sense. The most suitable measures for implementation can then be selected via an iterative process based both on potential impact and ability to implement.

Broad Scale Drivers of Adaptive Capacity

In addition to specific actions aimed at adapting to climate change impacts, there are broad cross-cutting drivers that can reduce sensitivity to GCC exposure and enhance adaptive capacity across the board. These include:

Controlling population growth.

Improving education.

Improving the performance of public agencies.

Creating non-agricultural employment.

In practice, structuring the adaptive process such that it is a series of graduated steps is often appropriate; beginning with screening to identify exposures, sensitivities, impacts, and adaptive capacities, followed by more detailed analyses in critical areas. All stages should involve extensive consultation with local stakeholders[12].

5.2 Indicative priorities

One important dimension of priority setting is related to geographic considerations. There is wide agreement that certain regions of the developing world will be more strongly affected by negative hydrological effects than others. In general, the Mediterranean region, Central America, Southern Africa, the Middle East, Sub-Saharan Africa, and the Indian subcontinent are likely to be strongly affected (see box). Within these regions of vulnerability lies great variability, thus assessing adaptation priorities for particular areas will require country and region-specific analysis.

As indicated earlier, however, the expected water-related impacts of global warming are not unique and will often simply build on and exacerbate current trends and emerging problems. The foregoing analysis, coupled with the conclusions of the recent Comprehensive Assessment of Water Management in Agriculture (IWMI, 2007), leads to the identification of several strongly recommended priorities with widespread applicability.

5.2.1 Water scarcity

The first strong priority is to develop measures to deal with growing water scarcity and increased variability of supply. In many of the most vulnerable regions, this is already a

[11] For example, migrating salmon is important to many Native American tribes in the Pacific Northwest.

[12] See USAID (2007) for a practical step by step approach to including climate change impacts in development project design. UNDP (2005) provides a more conceptual approach to this task.

problem which climate change impacts are very likely to exacerbate. This suggests that measures to alleviate existing or impending water scarcity would also be beneficial to ameliorating similar climate change impacts. Such measures include steps to both manage demand for water and to enhance supply. This is very important. It means that we need not wait for ex post evidence of change and precise estimates of its magnitude before beginning to act, since action will be beneficial even in the absence of climate change impacts.

Applying the Assessment Process

Many of the steps suggested in the assessment process described here have been applied in developed countries, as for example in California and the Murray-Darling Basin in Australia. In moving the process to a developing country setting the following characteristics should help guide location selection:

Strong national commitment to engage in a purposeful adaptation process.

—

A local scientific capacity which, with support, can carry out the modeling and other studies required to drive the process.

—

A wide range of possible water-related impacts on the country's socio-economic and environmental systems.

5.2.2 Knowledge base and analytic capacity

Another important priority is to expand the knowledge base on water resources, climate change exposure and impacts, and to strengthen national analytic capacity. Such knowledge is useful and important regardless of the exact magnitude of the hydrological impacts to come. Important knowledge gaps often include quantification of the elements of the hydrologic system, including inflows, outflows, storage, and use of both surface and groundwater. The capacity to adapt and use regional climate and hydrologic models is also a critically important adaptive skill for a country to have. Agricultural research on drought-resistant or heat-tolerant cultivars, in coordination with international agricultural research centers, is another important adaptive measure.

5.2.3 Integrated planning and management

A further strong priority is strengthening capacity for integrated water resource planning and management. Such capacity will be beneficial under a wide range of climate impact scenarios. Integrated planning to deal with shrinking water availability and expanding demand for water is the bridge that translates knowledge into action. Emphasis should be on both strengthening planning and management tools and on developing mechanisms for broad stakeholder participation in the planning process.

5.3 Strategy for adaptive action

The key priorities identified above suggest a number of specific areas for adaptive action. Adapting to water scarcity is particularly rich in possibilities. Other actions can help integrate climate change impacts into ongoing planning and management processes, and enhance the knowledge base for planning and management. Most of these are "no regrets" measures that will have a benefit regardless of the exact path climate change follows in the coming decades. Many of these actions will take time to bear fruit, and so it is important to begin with them early.

5.3.1 Integrate climate change into planning

Evidence suggests that planning for the impacts of climate change alone is not nearly as useful as integrating climate change considerations into more comprehensive planning routines. This is an important action item in terms of enhancing capacity to deal with emerging hydrological impacts of climate change. Doing this effectively will necessitate several measures. One is simply to build the capacity to undertake regional climate modeling and hydrological impact assessment within a country. Another is to link the various analysts and institutions working on water-related planning across institutional boundaries. This may be a greater challenge. Executive branches of government can also require that ministries and departments: include climate change impacts into their planning processes; and report regularly on measures being undertaken and their impact.

5.3.2 Water resources knowledge base

In many of the countries expected to experience growing water scarcity due to climate change and ongoing population and economic growth, the water resources knowledge base is rudimentary. Basic figures on water resource availability, variability, and use are lacking or badly outdated. This is a primary prerequisite for logical decision making on which adaptive measures to implement. Application of Geographic Information System (GIS) and remote sensing technologies to the assessment process can enhance the accuracy and extent of coverage considerably. In addition to building up the knowledge base itself, it is equally important to develop capacity within at-risk developing countries to prepare national water budgets, assess hydrological impacts of changes in climate parameters, and assess vulnerability and adaptive capacity.

5.3.3 Water-saving technology

Adoption of water-saving technology by farmers for irrigation purposes is a key adaptive response to scarcity. Drip irrigation is a scalable technology that is just as appropriate for a woman tending a 0.2 hectare vegetable plot as it is for one growing 25 hectares of orange trees, and it has enormous water-saving potential. Other possibilities include converting open, earthen channels to buried pipelines and adding control gates to free flowing systems. In the area of domestic water supply, there are also technologies for reducing water use, such as low volume toilets, low flow showerheads and metering. The private sector should generally be the party to market these technologies. Innovative groups, such as Denver-based IDE[13], provide early support to nascent manufactures and sellers of very small-scale irrigation and domestic water supply equipment before they graduate into larger private operations. The International Commission on Irrigation and Drainage (ICID) has developed a list of ten strongly effective technologies for increasing agricultural production with limited amounts of water[14].

5.3.4 Management and governance reforms

In addition to technological improvements, often complementary reforms in the management and governance of water distribution offer the promise of more efficient water use, and more responsive adaptation to reduced future supplies. These would include transfer of irrigation system management responsibility from the state to farmers, and private sector involvement in operating municipal water supply systems. Establishing reliable systems of water rights is also an essential tool for allowing future water shortages to be allocated more equitably. Private sector marketing of water-saving equipment and private extension activities can also be a part of such reforms.

5.3.5 Supply augmentation

Investment in supply augmentation will almost certainly be necessary in many regions as global warming progresses. However, decision makers may be understandably reluctant to commit to such investments until the parameters governing rainfall volume and distribution are better specified. Nonetheless, alternative non-conventional water sources, such as urban wastewater streams, are sure to become increasingly valuable with time. They currently cause severe environmental degradation and are often used for irrigation regardless of their poor quality. Investments in treating urban wastewater are a “win-win” solution for dealing with expected climate-induced water shortages, as well as several current problems. An important area for research and development is the use of “constructed wetlands” for treating wastewater streams from smaller communities in warmer climates.

Enhanced groundwater recharge is another promising way of stabilizing water supplies in the face of growing variability. There are a variety of techniques for artificially in-

13 International Development Enterprises, http://www.ideorg.org/

14 www.icid.org

creased storage of rainfall and surface flows underground, for withdrawal during drier periods in the year. Experiences such as those in India with village-level recharge programs should be evaluated for possible application elsewhere.

5.3.6 Multiple uses of water

Multiple uses of water have recently received attention under the CGIAR's Challenge Program for Water and Food and have been highlighted by the Bill and Melinda Gates Foundation and others. Multiple use strategies are concerned with systems that can support a variety of productive activities, (e.g. as related to irrigated crops, livestock, poultry, and aquiculture), as well as domestic water supply and environmental needs, rather than with just a single use. Research has shown this to be a promising approach warranting further attention. This idea has particular relevance in SSA, where considerable new investment in irrigated agriculture is foreseen.

Projected Regional Impacts

In Africa, by 2020, between 75 and 250 million people will be exposed to increased water stress.

—

In Africa, by 2020, in some countries yields from rainfed agriculture could be reduced by 50%.

—

In Asia, by the 2050s, freshwater availability in Central, South, East, and Southeast Asia, will decrease, particularly in large river basins.

—

In Asia, heavily-populated megadeltas in the South, East and Southeast will be at risk due to increased flooding from the sea and rivers.

—

In Latin America, productivity of some important crops will decrease and livestock productivity will decline, with adverse consequences for food security.

IPCC, 2007c

5.3.7 Agricultural research

The CGIAR[15] centers are already engaged in research aimed at identifying and combating the harmful effects of climate change on crop and livestock agriculture[16]. They have mapped the impact of climate change on maize and wheat production in important producing areas, developed "climate-resistant" varieties of cereals and pulses, and created a type of "waterproof" rice that will withstand complete submergence during floods for up to two weeks. National research and extension systems need to forge links and collaborate with these ongoing international research efforts.

5.3.8 Insurance schemes

There is scope for insurance programs to smoothen the risks associated with climate variability. Primary targets would be risks relating to crop failure, livestock deaths, and floods. It is important to note, however, that potential buyers of insurance policies that are "less" vulnerable will generally be unwilling to share risks with "more" vulnerable ones. Consequently, risk pooling will likely occur across time rather than among say urban and rural policyholders. Moreover, insurance schemes can only smooth variability, and cannot compensate for longer-term changes in levels of precipitation, temperature, etc. In other words, insurers will have to build into their risk calculations longer-term secular changes in values for climate variables. This will likely involve steadily increasing premiums for policies over a time period in which average agricultural productivity may well be falling.

5.3.9 Awareness

While there is widespread and growing awareness of global climate change as a threatening worldwide problem, there is much less understanding of the mechanisms that drive the problem and the options available both to mitigate it and to adapt to it. It is important to raise awareness among policy makers, opinion leaders, and the general public in this regard. Policy roundtables, seminars, conferences, and news features are all effective ways of doing this. Climate change can also be included in school curricula at all levels.

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[15] Consultative Group on International Agricultural Research

[16] http://www.cgiar.org/pdf/cc_mappingthemenace.pdf

6

Role for Development Cooperation in Supporting Adaptive Action

Addressing hydrological impacts of climate change is an important issue for international cooperation. Water is a core development sector and water is also a cross-cutting issue, relating both to many climate change impacts and to many development objectives, including poverty reduction, health and food security. Current adaptive capacities in developing countries are often low, calling for international support.

Developing countries' demand for financial and technical support for adaptation in water resources is expected to rise considerably. The most comprehensive assessment of financial flows needed for adaptation, conducted by the United Nations Framework Convention on Climate Change (UNFCCC 2007), estimates that an additional 9 billion US dollars will be needed in 2030 to adapt the water sector in developing countries to the effects of climate change. In Least Developed Countries, water-related issues were identified among the most important priorities in many National Adaptation Programmes for Action prepared under the UNFCCC (Agrawala et al., 2008; Osman-Elasha/Downing, 2007).

Supporting developing countries in addressing climate change impacts is a question of fairness, as industrialised countries have largely caused the greenhouse gas effect. In view of the enormous scope of the problem, development cooperation can only contribute a part of the resources necessary for adaptation. Additional international funds will be required. Supporting governments in formulating adaptation strategies and setting priorities is an essential task for development cooperation. Moreover, it will be important to target the most vulnerable regions, groups and sectors. Often it is those parts of societies that are already marginalised (e.g. subsistence farmers, herders, inhabitants of informal settlements) that will be affected most strongly by climate change due to strong exposure and low adaptive capacity.

6.1 Areas of intervention for building adaptive capacity

There are many starting points for development cooperation to support adaptive action and strengthen adaptive capacity for addressing hydrological impacts of climate change.

Firstly, development cooperation has a large portfolio that already contributes to increasing adaptive capacity in the water sector. The approach of Integrated Water Resources Management (IWRM) has been geared towards moderating and coordinating interests of all water users, and this can be a useful framework for adaptation approaches building on a multi-stakeholder and multi-sector approach and having a strong planning component. Improving efficiency of water use has long been an important area of interventions, not because of climate change, but in order to achieve sustainable use of water resources in view of rising populations and water scarcity. Moreover, many inputs of technical cooperation, capacity building and financial cooperation in the water sector have contributed to improving adaptive capacity in terms of improving infrastructure, analytical and organisational capacities, providing incentives for sustainable water use and much more. Development cooperation can contribute further to adaptation by extending this type of work as will be explained below. Such options can be considered "win-win" or "no-regret" options as they yield benefits independently of climate change. The close link between development interventions in the water sector and adaptation make it clear that it is crucial to integrate the adaptation agenda into existing strategies.

Transboundary water management in Southern Africa

Southern Africa will be one of the regions most severely affected by a decrease in rainfall, increase in temperatures and therefore lower available water resources. Within the context of the Southern Africa Development Community (SADC), GTZ is supporting transboundary water management in the river basins of Orange-Senqu, Limpopo and Kunene, with co-financing from DFID since 2008. The SADC Water Division is implementing its Regional Strategic Action Plan (RSAP) for the whole SADC region, and GTZ is supporting the Water Division in incorporating adaptation strategies into the RSAP. In addition, adaptation strategies are also being integrated into the Integrated Water Resources Management Plans that the Basin Commissions for the Orange-Senqu and the Limpopo are currently developing. And the personnel of the SADC Water Division are being trained in providing advice and institutional support to river basin organisations, thus strengthening the adaptive capacity of basin organisation staff.

Secondly, a growing body of knowledge and experience on specific adaptation practices is available as adaptation to climate change has become an important development cooperation issue. Targeted adaptation interventions in a particular setting can be achieved by basing adaptation strategies on knowledge about expected changes to the hydrological cycle due to climate change. Specifically, an adaptation strategy requires assessing climate change impacts, vulnerabilities, adaptation options and implementation issues. Supporting developing countries in improving data bases and analytical capacities, e.g. in assessing hydrological impacts of climate change as well as their secondary economic and social impacts, vulnerability assessment, applying decision making tools, and developing planning approaches and strategic processes are possible contributions of development cooperation. This enables identification of adequate adaptation technologies and governance settings for their successful application. Yet, because the driver - global warming - and the impacts are evolving under uncertainty, adaptive responses must be iterative and robust. Turnkey approaches which assume clear understanding of the final state of affairs are inappropriate.

Relating to the indicative priorities and elements of a strategy on adaptive action presented above, concrete areas where development cooperation can support capacity building including the following:

6.1.1 Policy analysis and change

As national and sectoral policies set the framework for individual and collective adaptation responses, in a multi-level approach, policy advice is an entry point for stimulating supporting conditions. Basing water strategies, water master plans, or integrated water resources management plans on climate projections and building in adaptation responses is necessary to sustain water supply and quality under changing climate conditions. Adaptation in the water sector will imply altered and new investments in (often public) infrastructure. Medium Term Expenditure Frameworks (MTEF), Poverty Reduction Strategy Papers (PRSP) and other types of development plans will therefore need to undergo adjustments, and integrating adaptation planning is necessary in order to secure sufficient financial resources to implement adaptation. Moreover, through proper analysis and prioritising activities, efficiency of public spending and investments can be enhanced. With regard to floods, spatial planning and building codes may need to be adjusted. Introducing the adaptation issue into planning and management procedures of regional institutions such as SADC or river basin commissions such as the Niger Basin Authority may be equally important. National, sectoral, or regional adaptation strategies, analysing impacts of and vulnerabilities to climate change, adaptation options and priorities can help to

- provide a framework for coordinating adaptation activities,
- create a vision on adaptation priorities and on mid to long term perspectives for adaptation,
- enable informed decision making based on information about vulnerabilities, impacts and adaptation options,
- raise awareness,
- mobilise support in the country as well as from the international community,
- provide the ground for adequate institutional structures for adaptation.

To facilitate policy changes, development cooperation can contribute to improving adaptive capacity through provision of expertise in the area of climate and climate impact data. It can help to build up analytical and monitoring capacities, provide and introduce tools for assessing policies - including cost benefit analysis and climate proofing procedures - , as well as moderate and support processes of strategy development and concertation. This may also include longer term economic strategies for particular water users and sectors (e.g. agriculture) to adjust to expected water availability.

6.1.2 Infrastructure development and technology

Many of the indicative priorities and strategy elements identified above relate to infrastructure development and technologies. Efficient water use can be supported through water saving technologies like drip irrigation, reducing water losses in water networks and canals, reducing evaporation and runoff on agricultural land through crop cover and cropland management, optimised water allocation, multiple use systems and methods of rainwater harvesting. Protecting existing water resources through wastewater treatment and controlled landfills are other available technologies. Physical infrastructure will be most relevant to augmenting storage capacity and to flood protection. Storage capacity can be increased through dams and reservoirs, constructing earthwork along contour lines, protection of wetlands and floodplains, artificial groundwater recharge and reforestation. Infrastructure and technologies may also support disaster prevention through drainage systems, dykes, improved regulation of reservoirs, floodplain management and flood protection facilities. Finally, information and monitoring systems including data collation, modelling and analysis, are technological needs.

There are important roles of financial cooperation in funding and designing water-related infrastructure, but also non-structural measures. Roles of technical cooperation would include capacity building for hydrological and meteorological services, agricultural extension services and water manag-

Development of water sector master plans in the Middle East

Already a semi-arid zone, the Middle East will have to live with even less available water for its growing population, given IPPC projections. Especially under such conditions, planning for sustainability is a key challenge for water sector professionals. Therefore, GTZ supports the development of water sector master plans and baseline reports in several countries, such as Syria and Jordan. The National Water Master Plan of Jordan, which was first presented in 2004, had already incorporated the possibility of calculating projections for water resources availability and demand based on drought scenarios. In Syria, GTZ supports the development of a first baseline Water Sector Report, which also comprises a volume on climate change. In this volume, current knowledge on impacts of climate change is analysed to determine policy implications and recommendations for adaptive management. The resource information comprised in these reports and plans is also needed in regional climate modelling and subsequent development of adaptation strategies. Based on these plans and strategies, decision makers in the water sector of the Middle East are enabled to give their sector orientation towards sustainability under a climate change scenario.

Adapting water management to climate change in Northern Peru

In Peru, melting Andean glaciers are causing lasting changes in the nation's hydrology, and extreme weather events are becoming more frequent and more intense. Since 2007, GTZ has been advising and supporting a pilot project in Piura, aimed at enhancing the capacity of local actors to integrate adaptation to climate change into planning and public investment processes and management of local water resources. The project also supports climate sensitive agricultural value chain creation and environmental education. Accomplishments include:

Identifying priority adaptation measures and institutional responsibilities for implementing them in a participatory process

—

Identifying alternative crops that are better adapted to expected future climate conditions and designing water-saving irrigation schemes

—

Holding expositions to raise public awareness of expected climate changes

—

Introducing climate change into the curriculum for all school levels

—

Integrating knowledge of expected hydrologic impacts of climate change into watershed management.

ers taking into account climate changes, supporting regional cooperation, introducing payments for environmental services to protect water resources, managing protected areas, supporting participatory irrigation management, etc. Pilot projects may be suitable for developing best practices and demonstrating their feasibility.

6.1.3 Changes in management and governance

Climate change requires adjustments of natural resources, planning of settlements, infrastructure, and economic activity, as well as increased flexibility and risk management, changes in management and governance will be necessary. Constant adjustments based on monitoring and climate modelling will need to inform water resources management. Intersectoral coordination will gain importance. This has considerable governance implications. National committees, task forces or working groups on climate change may provide a platform for coordination between sectors and identifying cross-sectoral issues such as planning principles or provision of climate data. Many countries have already set up such institutions. Administrative reforms may be necessary to allow for the necessary coordination between sectors as well as between different administrative levels and to enable the flexibility required. For instance meteorological services and climatologists will need to work more closely together with water planers, irrigation managers or agricultural extension services. Regional coordination in controlling river flows in order to avoid floods and water shortages is an example of coordination across levels. Institutions for water resources management following the IWRM approach may be a model or entry point, where they exist. It is also obvious that the adaptation issue, affecting all sectors, needs to be placed in the mainstream of decision-making and not just be advocated only by environment ministries, as is still the case in some countries.

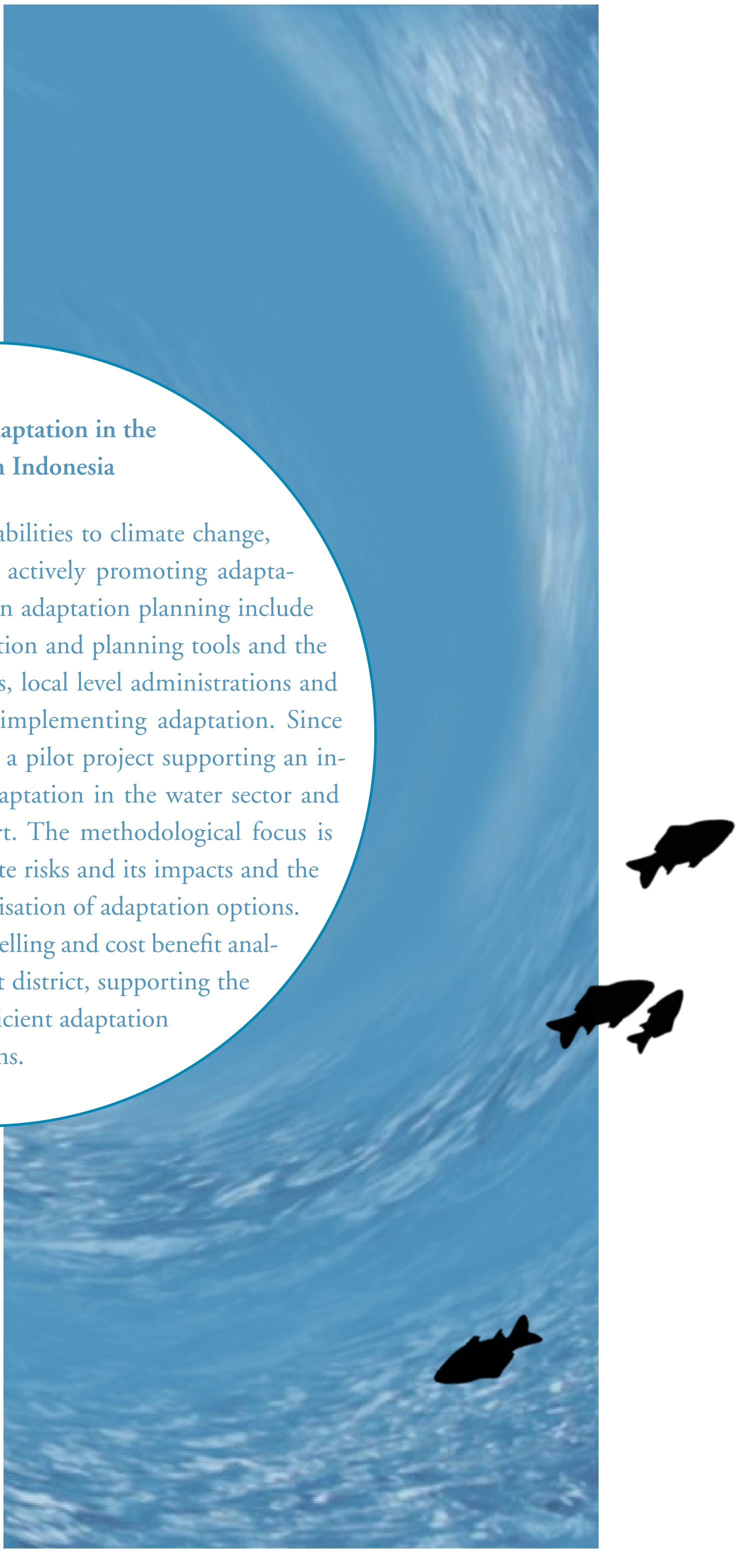
In order to bring about adaptation at all levels, incentives that shape individual behaviour are necessary. Where adaptation can be achieved through private sector decisions (e.g. improving efficiency of water use), governance structures and incentives need to address and integrate the private sector. Moreover, civil society needs to be involved where it is affected, e.g. in the development of adaptation strategies.

Development cooperation has a role to play in facilitating reform processes, supporting institutional coordination and cooperation, and moderating national and regional cooperation. It can contribute to improving incentives for adaptation e.g. through supporting demand-side management, assisting with climate sensitive assessments in planning and pricing of resources and strengthening participatory management systems. Development cooperation has longstanding experience in disaster prevention, which needs to be applied and adjusted to the climate change challenge.

6.2 Adaptation to hydrological impacts of climate change in GTZ's work

Many measures that are suitable instruments in an adaptation context have been applied by GTZ in water programmes. Their application was usually not actively planned in an adaptation context. This can be explained by the fact that GTZ projects and programmes operating today were usually planned three to five years ago, at a time when most countries in the developing world had neither any thorough scientific base for climate change scenarios nor existing adaptation strategies for the water sector. Moreover the level of awareness of the looming impacts of climate change has grown exponentially over this period in both developed and developing countries. Therefore, measures such as transboundary planning for water resources management might have been applied and contributed to the adaptation purpose without being labelled as such.

Today, this situation has changed. Experience on adaptation has been built up in specific adaptation pilot activities and climate change considerations are increasingly being introduced into water programmes. Many measures being planned within GTZ's water portfolio are geared towards the adaptation priorities and context of our partner countries. They will, over the course of the coming years, for example support the development of adaptation action plans, the development of adaptive capacities in our partner institutions and more technical approaches, such as the application of rainwater harvesting techniques on a local level. Finally, water being a cross-cutting issues, hydrological impacts of climate change are increasingly being addressed in projects in related secotrs, e.g. in agriculture and natural resource management.



Mainstreaming adaptation in the water sector in Indonesia

In view of Indonesia's vulnerabilities to climate change, the Indonesian Government is actively promoting adaptation programs. Challenges faced in adaptation planning include the availability of relevant information and planning tools and the active involvement of line ministries, local level administrations and other stakeholders that are key to implementing adaptation. Since 2007, GTZ has been implementing a pilot project supporting an interministerial working group on adaptation in the water sector and providing decision-making support. The methodological focus is on assessing vulnerability to climate risks and its impacts and the economic assessment and prioritisation of adaptation options. Climate and hydrological modelling and cost benefit analysis are performed in a pilot district, supporting the identification of efficient adaptation options.

References

Allen, L. H. Jr., J. C. V. Vu, and J. Sheehy. 2008. Transpiration: carbon dioxide and plants. Encyclopedia of Water Science. Taylor and Francis. New York.

Barnett, T. P., D. W. Pierce,H. G. Hidalgo, C. Bonfils,B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A.A. Mirin, D. R. Cayan, M. D. Dettinger. 2008. Human-Induced Changes in the Hydrology of the Western United States. Sciencexpress 31 January www.sciencexpress.org.

Bhadwal, S., P. Bhandari, A Javed, U. Kelkar, K. O'Brien, S. Barg. 2003. Coping with global change, vulnerability and adaptation in Indian agriculture. TERI, New Delhi. CGIAR. n.d. Adapting agricultural systems to climate change. CGIAR, Washington DC.

CGIAR. Mappoint the menace of global climate change. http://www.cgiar.org/pdf/cc_mappingthemenace.pdf

Cline, William. 2007. Global warming and agriculture: impact estimates by country. Center for Global Development, Washington D.C.

de Wit, Maarten, and Jacek Stankiewicz. 2006. Changes in surface water supply across Africa with predicted climate change. Science. 311(5769:1917-21.

Deressa, Temesgen Tadesse. Forthcoming. Measuring vulnerability of Ethiopian farmers to climate change across regional states. IFPRI Working Paper. IFPRI, Washington D.C.

European Commission. 2007. Adapting to climate change in Europe - options for EU action. Green paper. EC, Brussels.

Hansen, James; Sato, Makiko; Ruedy, Reto; et al. Global temperature change. PNAS 2006, 103 (39), 14288-14293.

IFPRI. 2006. How will agriculture adapt to a shifting climate? IFPRI Forum, December. IFPRI, Washington D.C.

IIED. 2007. Issues paper: water ecosystem services and poverty reduction under climate change. IIED, London. Draft

IPCC. 2007a. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. 2007b. Freshwater resources and their management. Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 173-210.

IPCC. 2007c. Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7-22.

Lobell, D., M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor (2008) Prioritizing climate change adaptation needs for food security in 2030. Science 319, 607-610.

Milly, P. C. D., K. A. Dunne, and A. V. Vecchia. 2005.

Global pattern of trends in streamflow and water availability in a changing climate. Nature 438(17):347-350.

Milly, P. C. D., Julio Betancourt, Malin Falkenmark, Robert M. Hirsch, Zbigniew W. Kundzewicz, Dennis P. Lettenmaier, Ronald J. Stouffer. 2008. Stationarity Is Dead: Whither Water Management? Science 319, 573-74, www.sciencemag.org.

MWD. 2007. Investing for the future. Annual progress report to the California State Legislature: achievements in conservation, recycling and groundwater recharge. Metropolitan Water District of Southern California, Los Angeles, CA.

Magrath, John, and Andrew Simms. 2006. Africa - up in smoke 2. New Economics Foundation, London.

National Research Council. 2008. Prospects for Managed Underground Storage of Recoverable Water. National Academy of Sciences, Washington, DC.

Nhemachena, Charles, James Benhin, and Glwadys Gbetibouo. 2006. Vulnerability to climate change and adaptive capacity in South African agriculture. IFPRI, Washington D.C.

Pak Sum Low. 2005. Climate change and Africa. Cambridge University Press, Cambridge.
Ohio State University. 2007. Climate change could diminish drinking water more than expected. http://researchnews.osu.edu/archive/saltwatr.htm

Shewmake, Sharon. n.d. Vulnerability to climate change in "South Africa's Limpopo River Basin. IFPRI. Washington D.C.

Smit, Barry, and Johanna Wandel. 2006. Adaptation, adaptive capacity and vulnerability. Global Environmental Change, 16 (2006): 282-292.Stern, Nicholas. 2007. The economics of climate change. Cambridge University Press, Cambridge.

Sperling, Frank, managing editor. 2002. Poverty and climate change, reducing the vulnerability of the poor through adaptation. AfDB, ADB, DfID, EC, BMZ, MA-DC (Netherlands), OECD, UNDP, UNEP, WB. Publisher unknown.

UNFCCC. 2007. United Nations Framework Convention on Climate Change (2007): Investment and financial flows to address climate change. Bonn.

USAID. 2007. Adapting to climate variability and change, a guidance manual for development planning. USAID, Washington D.C.

Acronyms

CGIAR	Consultative Group on International Agricultural Research
CO_2	Carbon dioxide
ENSO	El Niño-Southern Oscillation
EC	European Commission
EU	European Union
GCC	Global climate change
GCM	Global circulation model
GHG	Greenhouse gasses
GIS	Geographic Information System
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
ICID	International Commission on Irrigation and Drainage
IPCC	Intergovernmental Panel on Climate Change
MDGs	Millennium Development Goals
MUS	Multiple Use Systems
MWD	Metropolitan Water District (of Southern California)
MWRI	Ministry of Water Resources and Irrigation (Egypt)
SSA	Sub-Saharan Africa
UC/Davis	University of California at Davis

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