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Water and climate change impacts and adaptation strategies

Technical paper

Summary

Building on recent reviews on climate change impacts on freshwater resources and adaptation strategies, this technical paper analyses existing scientific information on observed and projected impacts of climate change on water, provides information on links between climate change and freshwater resources and on adaptation to climate change in the water sector. Parties may wish to use the information contained in this technical paper as they consider implementing adaptation action under the Convention, including in the work under the Nairobi work programme on impacts, vulnerability and adaptation to climate change.

Contents

I. Introduction

A. Mandate

1. At its thirty-fourth session, the SBSTA requested the secretariat to prepare, before its thirty-fifth session, a technical paper on water and climate change impacts and adaptation strategies under the Nairobi work programme (see box 1 for background information on the Nairobi work programme).[1]

2. This technical paper draws on available literature on the subject and attempts to synthesize relevant aspects of previous work on freshwater resources and climate change impacts and adaptation strategies and to identify a way forward. The paper aims to raise the level of understanding among Parties with regard to the links between climate change and freshwater resources, in a manner that would ultimately support informed decisions on practical adaptation action and measures on water resources.

B. Background

3. Water managers and relevant stakeholders seek to identify and implement appropriate, cross-sector and sector-specific adaptation measures. Bates et al[2] enumerate other policy areas influenced by water resource management, including energy, health, food security and nature conservation, and propose that the appraisal of adaptation and mitigation options should ideally be conducted across multiple water-dependent sectors. Given the intrinsic linkage between freshwater resources and other sectors and ecosystems, increased vulnerability in relation to freshwater resources will inevitably affect other sectors and ecosystems. Current water management practices may not be robust enough to cope with the impacts of climate change on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems.[3] This assertion that water occupies a unique position within the broader climate change process provides an important backdrop for the paper.

Box 1
Introduction to the Nairobi work programme

The Nairobi work programme on impacts, vulnerability and adaptation to climate change was adopted by the Conference of the Parties at its eleventh session, in 2005. Under the Subsidiary Body for Scientific and Technological Advice (SBSTA), the objective of this work programme is to assist all Parties, in particular developing countries, including the least developed countries and small island developing States to:

- Improve their understanding and assessment of impacts, vulnerability and adaptation to climate change;
- Make informed decisions on practical adaptation actions and measures to respond to climate change on a sound scientific, technical and socio-economic basis, taking into account current and future climate change and variability.

The implementation of the work programme is structured around two broad themes: impacts and vulnerability; and adaptation planning, measures and actions. Under these

[1] See: FCCC/SBSTA/2011/2.

[2] Bates B, Kundzewicz Z, Wu S and Palutikof J (eds.). 2008. *Climate Change and Water*. Intergovernmental Panel on Climate Change (IPCC) Technical Paper VI. Geneva: IPCC Secretariat.

[3] As footnote 2 above.

themes, the following nine action-oriented areas of work were identified:

1. Methods and tools;
2. Data and observations;
3. Climate modelling, scenarios and downscaling;
4. Climate-related risks and extreme events;
5. Socio-economic information;
6. Adaptation planning and practices;
7. Research;
8. Technologies for adaptation;
9. Economic diversification.

The Nairobi work programme was designed to facilitate knowledge sharing and learning, and to catalyse actions in relation to adaptation to climate change by engaging a wide range of stakeholders. The SBSTA mandates the organization of a series of knowledge-sharing events under the Nairobi work programme and encourages the broad participation of all adaptation stakeholder groups, and the development and dissemination of a diverse range of knowledge products. In the course of its implementation, the Nairobi work programme has provided a principal platform within the UNFCCC process for dialogue between Parties and organizations on the scientific, technical and socio-economic aspects of adaptation to climate change.

4. This technical paper explores how the evolving insights on the links between climate change and water resources can be integrated into the design and implementation of adaptation planning and practices. Consideration of non-climate related factors, such as urbanization and land-use change, is important given that the impacts associated with these changes can sometimes be more substantial than changes associated with a changing climate, particularly over the course of the coming one or two decades.

5. The decisions can be made in a meaningful way once these new insights are brought to bear within the standard practice of adaptation to climate change impacts on freshwater resources. This touches on issues related to data, modelling, knowledge and capacity.

C. Scope and approach

6. The technical paper explores links between climate change and hydrology, including impacts of climate change on: ecosystems and biodiversity, agriculture and food security, urbanization, land use and forestry, water supply and sanitation, health, infrastructure, and energy security which, in addition to climate, are strongly influenced by human interventions and actions. The paper also discusses the challenge of identifying and implementing appropriate adaptation responses by considering new approaches to adaptation planning and decision making.

7. Issues related to the links between climate change and associated hydrological change and potential impacts are addressed largely by reviewing and synthesizing available information, including that published by the Intergovernmental Panel on Climate Change (IPCC).

8. In terms of specific adaptation actions related to water resources, several documents provide useful information for summary and synthesis. The focus of these documents, however, tends to be on specific adaptation actions implemented in specific locations. While guidance documents have been proposed, such as the one by United Nations Economic Commission for Europe (UNECE),[4] there is no standard manual or guidance

[4] UNECE. 2009. *Guidance on Water and Adaptation to Climate Change*. Available at:

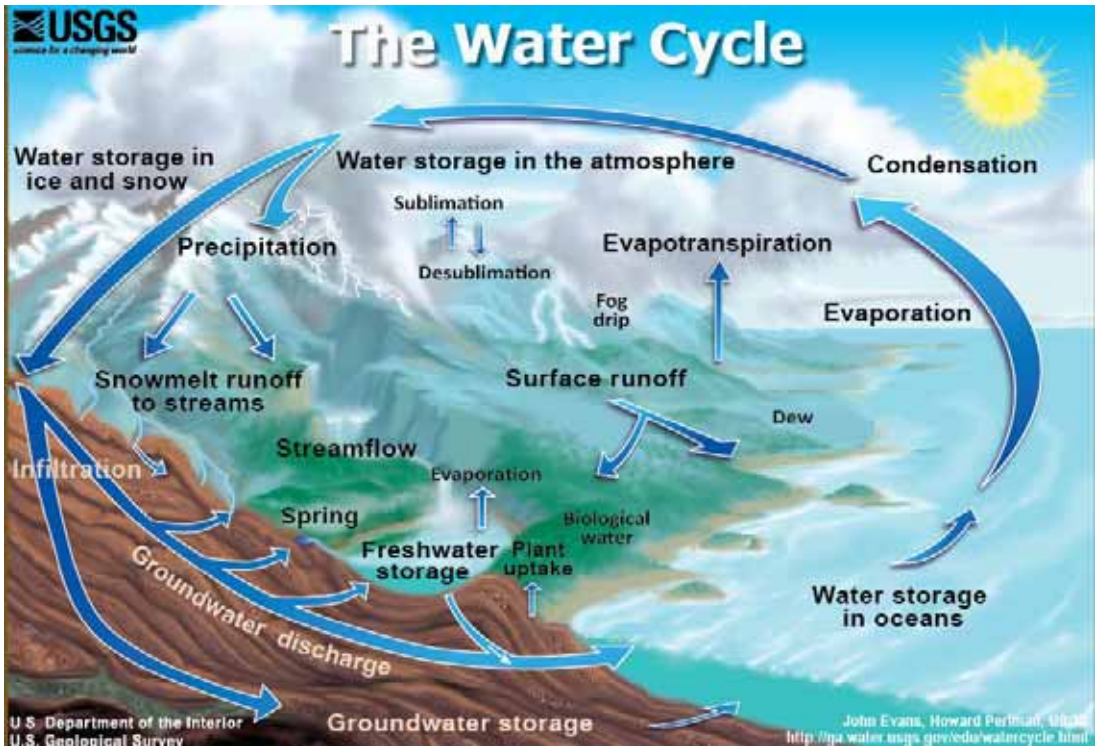
document on adaptation to climate change for freshwater resources, either to guide individual decisions taken on local scales or in terms of large infrastructure investments made within expansive and complex water systems.

9. Chapter II contains a review and synthesis of available information on links between climate change and freshwater resources, along with an assessment of potential impacts. Chapter III includes a review and assessment of adaptation strategies for freshwater resources, including processes under the Convention, and national and local initiatives. Needs and future priorities in adaptation to the impacts of climate change on water resources are examined in chapter IV. This is followed by conclusions in chapter V.

II. Impacts of climate change on water resources

A. Climate change and freshwater resources: the biogeophysical basis

Figure 1
Schematic representation of the water cycle



Source: U.S. Geological Survey/illustration by John Evans, Howard Perlman.

10. A growing body of information and knowledge pertaining to potential links between a changing climate and impacts on water resources is emerging. The graphical representation of the water cycle (figure 1) traces the paths travelled through time and space by the fixed quantity of water found on the planet. By convention, it is often assumed that the cycle begins with evapotranspiration, or the transformation of liquid water into water vapour through the process of evaporation from open water and the transpiration of water through the processes of plant respiration.

<http://www.unece.org/index.php?id=11658>.

11. Important climatic controls on evapotranspiration include temperature (positively correlated), relative humidity (negatively correlated) and wind speed (positively correlated). It is through the process of evapotranspiration that increasing global temperatures in the coming decades resulting from climate change would most directly affect water resources. Here it should be noted, however, that the increased levels of atmospheric carbon dioxide that will contribute to anticipated increases in greenhouse gas concentrations have the potential to counteract the effects of increasing temperatures. Uncertainty remains about potential future changes in evapotranspiration, as with much of the information on anticipated changes in the global climate system.

12. Potential evapotranspiration includes water that plants would transfer to the atmosphere given access to sufficient quantities of available water. The source of this available water is the soil moisture reserves accessed by plant roots. In the extreme, reductions in soil moisture can be substantial enough to limit respiration to the point that plants wither and die. Here is where potential changes in precipitation, as the source of soil moisture recharge, are important.

13. A critical feature of the water cycle is the partitioning of precipitation between surface runoff and infiltration. Precipitation falls in the form of liquid water, which immediately partitions between infiltration and surface runoff, or lead to the accumulation of snow and ice. Temperature determines the amount of precipitation that accumulates as snow and ice and the amount of time that water stays in those frozen forms before melting. Surface runoff can eventually join water flowing in rivers and streams and collecting in lakes and wetlands. Infiltrated water can become soil moisture that transpires or percolates below the root zones of plants, eventually to become part of groundwater stored in aquifers. In either case, water in rivers and streams or water in aquifers flows down the gradient, with the possibility that when surface water bodies and aquifers come into contact, there is the potential for an exchange.

14. The water cycle also influences the climate, primarily via the impact that water vapour, clouds and ice have on the radiation balance of the Earth. Freshwater inflows influence the density-driven ocean circulation and thus ocean–atmosphere interactions. These potential feedback cycles are the subject of much current research, which is guiding efforts to improve the ensemble of Atmosphere–Ocean General Circulation Models (AOGCMs)[5] that produce information on future global climate conditions. Output from ensembles of AOGCMs are typically used to offer hypotheses about the future, referred to as projections or scenarios, rather than predictions.

B. Regional expectations of future climatic and hydrological conditions and impacts of climate change on freshwater resources

15. The IPCC *Special Report on Emissions Scenarios* (SRES) relies on the results of a suite of AOGCMs, often referred to as an ensemble-analysis, to develop commonly used scenarios of climate change and subsequent impacts.[6] In terms of temperature, it is

[5] The AOGCMS are mathematical representations of Earth processes and are intended to provide only hypotheses about future climate, or projections, rather than predictions. While it is likely that future refinements and enhancements to the suite of AOGCMs employed by the IPCC will yield different expectations as to future changes in the global climate regime, and associated changes in hydrology, the best source of current information on the subject is contained in the materials produced by the IPCC Fourth Assessment Report (AR4). The AR4 AOGCM ensemble provides the most sophisticated set of climate models in terms of (a) the range of processes included and (b) the consequent realism of the simulations compared with observations.

[6] IPCC. 2000. *Emission Scenarios*. Nebojsa Nakicenovic and Rob Swart (Eds.). Cambridge University Press, UK. pp 570. Available at: <http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0>.

projected that global average temperature increases for the period 2080–2099 (relative to 1980–1999) are likely to range from 1.1 °C to 2.9 °C for the B1 SRES emissions scenario and from 2.4 °C to 6.4 °C for the A1FI scenario.[7] While regional variation exists within these global average ranges, it is reasonable to assume that the impact of temperature increases on potential evapotranspiration and the related changes in accumulation of snow and ice will be felt to some degree across the globe.

16. The AOGCM model results related to precipitation suggest that precipitation will generally increase in regions of current tropical maxima and at high latitudes, and generally decreases in the subtropics. Results from a 15-model ensemble show annual precipitation increases of more the 20 per cent for the 2080–2099 period (relative to 1980–1999) in most high latitudes, eastern Africa, the northern part of central Asia and the equatorial Pacific, and decreases of up to 20 per cent in the Mediterranean and Caribbean regions and on the subtropical western coasts of each continent. An additional insight pertaining to precipitation derived from a 9-model ensemble is that storm event intensity will increase almost everywhere, but particularly at middle and high latitudes, and that the number of dry days between storm events in the subtropics and the lower middle latitudes will increase. These results are important, as the water cycle is a continuous process driven by local conditions, not by annual totals.

17. On a regional scale, atmospheric circulation and local land-atmospheric feedbacks enhance climate variability. AOGCMs are of a resolution too coarse to reflect regional variability and reliably inform regional assessment of climate impacts. This has led to efforts to statistically and dynamically downscale AOGCMs to regional climate models. Regional-scale changes include:

(a) Warming will be greatest over land and at high northern latitudes; warming will be least over the Southern Ocean and parts of the North Atlantic, continuing recent observed trends;

(b) Reduction of snow cover area, increases in thaw depth over most permafrost regions and decrease in sea ice extent; in some projections using SRES scenarios, Arctic late-summer sea ice disappears almost entirely by the latter part of the twenty-first century;

(c) Very likely increase in frequency of hot extremes, heatwaves and heavy precipitation;

(a) Very likely precipitation increases in high latitudes and likely decreases in most subtropical land regions, continuing observed recent trends;

(b) Likely increase in tropical cyclone intensity; poleward shift of extra-tropical storm tracks with consequent changes in wind, precipitation and temperature patterns.

18. These are global in scale and offer long-term projections, leaving significant uncertainty as to what sort of changes might be expected on the local scale, motivating the need for the downscaling of AOGCM output through either statistical methods or the use of regional climate models. Uncertainties associated with both the AOGCMs and downscaling create challenges for water managers seeking adaptation strategies.

[7] The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Of the three A1 scenario family groups that describe alternate directions of technological change in the energy system, A1F1 describes fossil intensive. The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. (Source: IPCC *Report on Emissions Scenarios*, see footnote 6 above).

19. One of the most important impacts of climate change on water systems is its influence on river flow, or discharge. Correlation between changes in stream and river flow and projected climate change is very different depending on the area. In arid and semi-arid regions, because of the small difference between rainfall and potential evapotranspiration, any reduction in rainfall has serious implications for rivers, even causing them to dry up.[8] For example, de Wit and Stankiewicz[9] estimate that for regions in Africa with annual rainfall of under 500mm, a 10 per cent reduction in precipitation causes a 50 per cent reduction in runoff. Similarly, any small increase in precipitation could create new floodplains.

20. In regions where stream flow is seasonally variable, and where climate change is expected to increase variability, the resulting impacts are higher stream flow variability with a subsequent range of impacts for stream flow dependent sectors such as agriculture. In colder regions, stream flow is typically related to snow melt, and changes in precipitation and temperature will change the timing of melt, with a range of implications for reservoir storage, hydropower generation and downstream flood management.

21. Countries that rely on glacial melt will initially see an increase in stream flow, and then a sudden drop as glaciers accumulate snow much more slowly (or not at all); this is of particular concern for the Himalayan region.[10]

22. Climate change will affect groundwater levels through its influence on the amount of water available to aquifer recharge. Changes in annual rainfall as well as changes in the patterns of extreme precipitation events will affect availability of water for recharge.

23. As higher temperatures increase evaporation rates, recharge and groundwater discharge rates could be affected. In places where availability of surface water is expected to decrease, there may be an increased reliance on groundwater to meet demand.[11] [12] For example, in India, 50 per cent of water for irrigation is from groundwater. Higher reliance on groundwater, coupled with reduced groundwater recharge, could prove to have extreme adverse effects in some regions.

24. Flood frequency and severity is expected in regions where more precipitation is projected. However, even in regions where a reduction of mean annual rainfall is expected, extreme events could still be problematic. Not all flooding is bad – certain sectors and farming practices rely on seasonal flooding. Floods become a natural disaster when the timing and severity is unpredictable. For example, melting of glaciers and water accumulation in new glacial lakes can result in a sudden discharge of large volumes of water and debris in glacial lake outburst floods (GLOFs). In the Himalayas, GLOFs have already increased in number.[13] [14]

25. Reduced summer rainfall combined with increased potential evapotranspiration could lead to droughts. Changes in seasonality and variability are also likely to cause droughts. Middelkoop et al.[15] suggest that more frequent summer dry periods and reduced

[8] Ludwig F and Moench M. 2010. The impacts of climate change on water *In*: Ludwig F, Kabat P, Schaik HV and Valk MV (eds.). *Climate Change Adaptation in the Water Sector*. London: Earthscan.

[9] De Wit M and Stankiewicz J. 2006. Changes in surface water supply across Africa with predicted climate change. *Science*. 311(5769): pp.1917–1921.

[10] Barnett TP, Adam JC and Lettenmaier DP. 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature*. 438: pp.303–309.

[11] As footnote 2 above.

[12] As footnote 8 above.

[13] As footnote 2 above.

[14] As footnote 8 above.

[15] Middelkoop et al., 2001. Impact of climate change on hydrological regimes and water resources management in the Rhine Basin. Climatic Change. 49: pp.105–128.

summer melt and runoff will lead to low flows in all major European river systems. Low flows affect river navigation, ecosystem services, water quality, and water supply for agriculture, industry and municipal use. In regions with growing populations, where climate projects indicate reduced availability of water, shortages are likely to increase rapidly.[16]

26. With regard to information generated in the context of the UNFCCC process, Parties to the Convention have provided information on freshwater-related impacts and vulnerabilities in their national communications and national adaptation programmes of action (NAPAs).

27. A synthesis of submitted NAPAs indicated that floods and droughts form some of the most frequently reported climate change vulnerabilities by Least Developed Countries (LDCs).[17] The increased severity and frequency of droughts and the unpredictable rainfall patterns as reported by LDCs are expected to lead to reduced crop yields, loss of income for farmers, and famine and malnutrition. The flood-related impacts include: loss of life; destruction of infrastructure; crop losses; sediment pollution; loss of soil fertility; landslides and erosion; and energy insecurity (e.g. disruption of hydropower systems).

28. In their fifth national communications, Parties included in Annex I to the Convention (Annex I Parties) reported key climate change impacts relating to freshwater resources, including floods and water stress.[18] In addition, some Parties have expressed concern about the retreat of glaciers and the thawing of permafrost.

29. A review of the sixth compilation and synthesis of initial national communications submitted by Parties not included in Annex I to the Convention (non-Annex I Parties) indicated that, of the 122 national communications reviewed, water resources (in 76 countries) and agriculture (in 83 countries) are the most vulnerable sectors, especially among countries in Africa and the Latin America and the Caribbean regions. Non-Annex I Parties reported severe water supply problems caused by a rapid increase in population, growing demands from agriculture and industry, expanding urbanization, unabated pollution of water bodies and the effects of climatic variability and extreme events.[19] Given the complexity of and the interlinkages between freshwater resources and other sectors, the vulnerability of freshwater could easily put other resources at risk. Some Parties identified climate variability and change as being responsible for increases in the frequency and intensity of surface runoff, soil erosion, drought and pollution, and decreases in surface water/runoff and groundwater, with negative impacts on agricultural lands, grasslands and terrestrial and aquatic ecosystems.

30. A 2008 UN-Water[20] survey of national integrated water plans found regional differences in priority areas: in the arid parts of North Africa, groundwater, desertification and irrigation were the key areas, while Caribbean countries were more focused on water resources development. The different priority areas relate to the climate variability

[16] As footnote 8 above.

[17] The Least Developed Countries Expert Group and the Global Environment Facility and its agencies. 2009. *Least Developed Countries Step-by-step Guide for Implementing National Adaptation Programmes of Action*. Available at <http://unfccc.int/essential_background/library/items/3599.php?rec=j&priref=7051#beg>.

[18] The fifth national communications submitted by Annex I Parties can be found at <http://unfccc.int/4903>.

[19] The sixth compilation and synthesis report of initial national communications from non-Annex I Parties can be found at <http://unfccc.int/2709>.

[20] UN-Water is an inter-agency mechanism formally established in 2003 by the United Nations High-Level Committee on Programmes. UN-Water strengthens coordination and coherence among United Nations entities and non-United Nations partners dealing with issues related to all aspects of freshwater and sanitation. This includes surface and groundwater resources, the interface between freshwater and seawater and water-related disasters.

experienced in these regions and indicate future concerns, independent of climate change. Even without the additional challenges posed by projected climatic change, these regions will continue to struggle to secure sufficient water supply.

31. A substantial body of work has emerged on regional expectations regarding the potential impacts of these purely hydrological changes discussed above on various sectors that rely upon water resources as a vital input. Potential sectors of interest include ecosystems and biodiversity; agriculture and food security; land use and forestry; water supply and sanitation; health; urban settlements and infrastructure; energy supply and electricity generation; human security and livelihoods.

32. There is substantial regional variability in the potential impacts of these changes. Moreover, there is much uncertainty as to the magnitude of the potential impacts related to the uncertainties associated with the SRES emissions scenarios, the output of the AOGCMs and the hydrological models run using the output from AOGCMs, and the sector-specific assessment tools. Nonetheless, the findings led to the challenge of deciding how to make adaptation planning and decision-making in the face of the profound, yet deeply uncertain, impacts on freshwater resources that may accompany climate change.

Box 2
Vulnerability, exposure and sensitivity

The Intergovernmental Panel on Climate Change defines vulnerability as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity.

Vulnerability results from a combination of processes that shape the degree of exposure, sensitivity to stress and impacts, and resilience in the face of those effects. Sensitivity refers to the degree to which a household, group or system is affected by exposure to any set of stresses[a] and reflects the capacity of a population (or system) to anticipate and withstand the immediate impacts of a hazard.[b] Sensitivity is characterized by pre-existing conditions of the exposure unit that adaptation may improve or exacerbate. A successful adaptation process will require adequately addressing the underlying causes of vulnerability. An effective adaptation process would therefore hinge on the ability of livelihoods, which includes social networks, cultural traditions and activities that provide food and income, to be sufficiently flexible so that no adverse impacts of climate change on the social system are discernable.

[a] Clark WC, Jaeger J, Corell R, Kasperson R, McCarthy JJ, Cash D, Cohen SJ, Desanker P, Dickson NM, Epstein P, Guston DH, Hall JM, Jaeger C, Janetos A, Leary N, and Levy MA. 2000. *Assessing Vulnerability to Global Environmental Risks*. Discussion Paper 2000-12, Environment
and Natural Resources Program, Belfer Center for Science and International Affairs, Harvard Kennedy School.

[b] Pelling M. 2003. The Vulnerability Of Cities: Natural Disasters And Social Resilience. London: Earthscan.

1. Ecosystems and biodiversity

33. Given the role that temperature and water availability play in ecosystem function, climate change will influence aquatic ecosystems and biodiversity. In regions where precipitation is expected to increase, water levels in lakes, wetlands and rivers are also expected to increase in spite of increased evaporation, while the opposite will likely be the

case elsewhere. In areas where precipitation and runoff are expected to decrease, drying of streams and lakes for extended periods could reduce productivity.

34. While these hydrological changes are likely to occur, it is important to remember that ecosystems respond to changes in hydrology in complex and often non-linear ways through interactions between biotic and abiotic processes. This makes it difficult to project changes in aquatic biodiversity at the local level based solely on inferences derived from global climatic and hydrological assessments.

2. Agriculture and food security

35. Where the expected ratio of precipitation to evaporative demand is expected to decrease, rain-fed agricultural production is vulnerable to climate change (see box 2 for the definition of vulnerability). Projections of increased aridity across Mediterranean-type regions and the subtropics appear to be robust across different climate models. Even areas where increased precipitation could contribute to increased yields could be vulnerable to crop damage linked to heavy storm events, excessive soil moisture and flooding.

36. In addition, modelling studies show that beyond a certain level of warming (2–3 °C), yields are likely to suffer even in regions where increased levels of precipitation are expected. Future water deficits could prompt efforts to expand irrigated agriculture, currently accounting for 18 per cent of global cropped areas but providing half of global grain production, although this potential use of water could compete with other water management objectives

37. Coupling climate change with ongoing agricultural land expansion in arid areas leads to an increased vulnerability to climatic shocks.[21] Rangeland and livestock systems are also subject to impacts under a changing climate. Decreasing precipitation and increasing evaporative demand could reduce primary productivity of rangelands and associated livestock carrying capacity. Prolonged droughts could lead to loss of herds. Rangeland systems are vulnerable, as the loss of biomass leads to increased erosion and soil degradation, exacerbated by more intense storm events that leave the system unable to recover even during wetter periods. In higher latitude regions, warming and increased precipitation actually have the potential to increase grassland productivity. Even in areas where precipitation could potentially increase, shifts in the timing of rainy seasons can create extended dry periods which can stress agricultural systems, such as in Kenya where the period between the two annual rainy seasons is particularly challenging.

38. In terms of fisheries, negative impacts of climate change on both aquaculture and freshwater capture fisheries are likely because of increased temperatures and oxygen demand, along with extreme storm events leading to decreased water quality. These impacts will be exacerbated in regions where decreased precipitation results in declining water levels in lakes and rivers. In high latitudes, however, longer ice-free periods could allow for increased growth rates and food conversion efficiency.

39. Given that more than 80 per cent of global agricultural land is rain-fed, as reported by the Food and Agriculture Organization of the United Nations,[22] the projected changes in water quality and quantity due to climate change are expected to have a significant impact on the agriculture sector in terms of agricultural productivity, hence affecting food security.

40. Independent of climate change impacts on water, food insecurity is already a growing concern throughout developing countries. To keep up with the growing

[21] United Nations Environment Programme. 2007. *Global Environment Outlook 4: Environment for Development*. Available at <http://www.unep.org/geo/geo4/report/01_Environment_for_Development.pdf>.

[22] As footnote 2 above.

population, food production will need to increase by 50 per cent by 2030. Adding climate change to the equation could decrease global cereal production by 1–7 per cent by 2060 – particularly in South Asia and sub-Saharan Africa.[23] As regions gain and lose comparative advantage, countries could see a gradual shift in the level of reliance on trade to meet local food requirements. In the last five years, the world has experienced disruptions in regional food production systems with a ripple effect for production and trade. For example, failure of the monsoon in India or a major storm in China would affect regional food production, and the resulting demand to import grain would probably affect food prices as well as exceed the capacity of global markets to fill the deficit.[24] Between 2006 and 2008, global basic food staple prices rose dramatically, especially in Asia and Africa. Australia, the second largest wheat exporter after the United States of America, experienced a prolonged and intense drought, dramatically reducing its harvest. As a result of this crop failure and others, food prices doubled in some countries, countries imposed strict export bans to keep food at home, and in the most extreme of cases, there were civil unrest and protests.

3. Land use and forestry

41. Forests occupy roughly the same land area as cropped systems, with roughly 5 per cent managed commercially. Like other biomass, forests will react to changes in temperature and precipitation. In areas of sufficient soil moisture, increasing temperatures could increase forest productivity, while decreases in precipitation in other regions will have the opposite effect. Forests in areas characterized by warming and drying conditions may be at great risk of forest fire. Forests in Africa, for example, may become more vulnerable to climate change as a result of substantial land-use change, with forests in West and Southern Africa potentially experiencing declines in forest ecosystem goods and services.

4. Health

42. Changes in climate extremes, including reduced river flows and floods have the potential to cause severe impacts on human health. Bates et al[25] reports that flooding is expected to become more severe with climate change, and this will have implications for human health. Reduced river flows due to less rainfall could have implications for drinking-water quality. Health impacts due to flood include deaths and disease burden. Bates et al also reports that climate change is also expected to have a range of adverse effects on populations where the water and sanitation infrastructure is inadequate to meet local needs.

5. Water supply and sanitation

43. Climate change, combined with increasing population and urbanization trends, could result in between 0.4 and 1.7 billion additional people being exposed to conditions of water stress by 2020, 1.0 and 2.0 billion more by 2050 and between 1.1 and 3.2 billion more by 2080, depending on the emissions scenarios considered.[26] These figures are physical indicators based on some defined water stress threshold and do not consider the economic and social implications of constrained water supplies.

44. Universal goals to access freshwater resources will require effective and timely adaptation planning, policies and actions involving new water supply development and

[23] CARE International. 2011. *Adaptation and Food Security. CARE International Climate Change Brief.* Available at <http://www.careclimatechange.org/files/CARE_docs/CARE_Food_Security_Brief_2011.pdf>.

[24] As footnote 8 above.

[25] As footnote 2 above.

[26] Arnell N and Delaney K. 2006. Adapting to climate change: public water supply in England and Wales. *Climatic Change*. 78: pp. 227–255.

distribution and/or adjustments to demand, which could compete with other uses of water. Even where access is currently available, there is a risk of water quality degradation associated with increasing temperatures, low flows and increased contaminant inflow during more intense precipitation events. This will put stress on potable water services and increase the urgency of developing effective storm and wastewater management systems. An effective execution of water management for mitigating flood and public health disasters could also help to prevent slow-onset disasters.[27]

6. Urban settlements and livelihoods

45. The most pressing vulnerabilities associated with human settlements under a changing climate are associated with the lack of adequate water and sanitation services, as discussed above. Beyond this risk, however, the expansion of human settlements in areas prone to flooding associated with accelerating urbanization puts many people at risk from anticipated storm events of greater intensity. Transportation networks are also vulnerable to increased flooding in both developed and developing countries, with potential losses associated with delays and journey cancellations being overwhelmed by the physical damage that could occur in association with extreme weather events. Flooding also poses a risk to energy infrastructure, although low flow conditions in regions likely to experience decreases in precipitation could also threaten thermal plants that require water for cooling. Warmer air and water temperatures in these regions may also lead to conflict between the use and discharge of cooling water and efforts to protect aquatic ecosystems.

46. Several Nairobi work programme partner organizations have recognized the lack of adequate research on the relationship between freshwater systems and impacts on livelihoods.[28] Munang and Nkem address the intersection of human security and climate through the ongoing food crisis and famine in the Horn of Africa. Persistent droughts have destroyed local livelihoods, and 12 million people now lack access to clean water and sanitation; people's weakened capacity to respond to and cope with disaster also reduces prospects of food and water security in the future.[29] It is expected that temperatures in the region will rise and rainfall will be erratic.

III. Adaptation strategies for freshwater resources: review and assessment

47. Approaches to adaptation to the impacts of climate change on freshwater resources involve both top-down and bottom-up approaches (figure 2). Top-down methods involve cascades of information to support an assessment of impacts and possible adaptation actions.[30] [31] The process involves downscaling climate projections, resulting in local scenarios that are fed into impact models to estimate stream flow or agricultural yield, as an

[27] Muller M. 2007. Adapting to climate change: water management for urban resilience. *Environment and Urbanization*. 19(1): pp.99–113.
Available from:<http://eau.sagepub.com/cgi/reprint/19/1/99 DOI: 10.1177/0956247807076726>.

[28] See the UNFCCC publication *Climate Change and Freshwater Resources: a Synthesis of Adaptation Actions Undertaken by Nairobi Work Programme Partner Organizations.* Available at <http://unfccc.int/ 4628>.

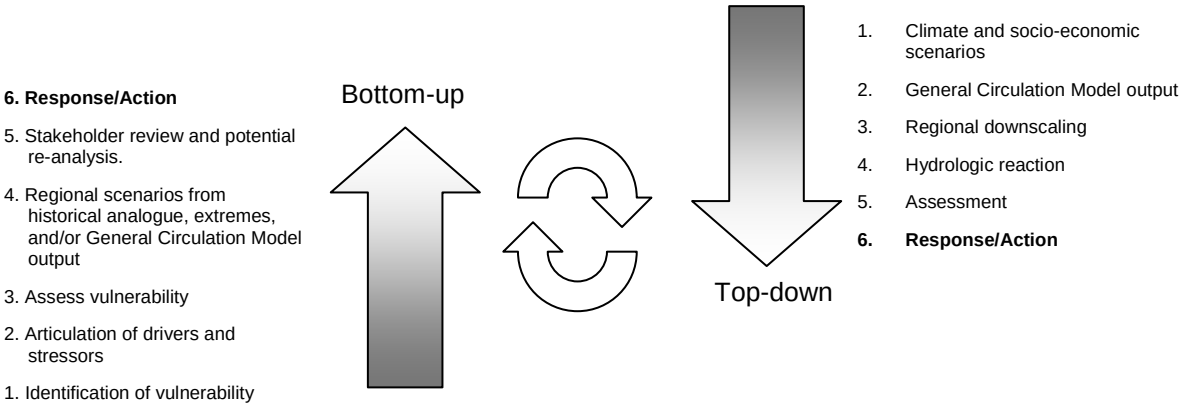
[29] Munang R and Nkem JN. 2011. Using small-scale adaptation actions to address the food crisis in the Horn of Africa: going beyond food aid and cash transfers. *Sustainability*. 3: pp.1510–1516.

[30] Wilby and Dessai, 2010. Robust adaptation to climate change. *Weather* DOI: 10.1002/wea.543. Wittfogel, K. 1957. *Oriental despotism; a comparative study of total power*. New York: Random House. doi:JC414 .W5:JC414 .W5JC414 .W5.

[31] Miller K and Yates D. 2006. *Climate Change and Water Resources: A Primer for Municipal Water Providers*. Denver: Awwa Research Foundation.

example.[32] Decision makers then seek to implement strategies that may improve system performance in the face of those impacts. Bottom-up methods focus on reducing vulnerability to past and present climate variability, typically in the wake of an extreme event or disaster such as droughts or floods with the expectation that building resilience to the vagrancies of the current climate will strengthen capacity to deal with change and extremes in the future. Bottom-up analysis begins with identifying the vulnerabilities of the system and the factors and conditions that enable successful coping with climate-related threats at the level of individuals, household, communities and organizations, and implementing strategies that enhance coping capacity, with the risk that these coping strategies may involve limited local knowledge and perception. There are real complementarities of the two methods, and developing specific policies and methodologies related to adaptation will require a blending of the approaches.

Figure 2
Schematic of bottom-up and top-down approaches to developing adaptation strategies



48. Work on adaptation so far has focussed more on addressing the impacts of climate change than the underlying factors that cause vulnerability to freshwater resources. A successful adaptation process needs to include adjustments in policies, institutions and attitudes that establish enabling conditions, accompanied by eventual technological and infrastructural changes.

49. An effective adaptation process would also hinge on the ability of livelihoods, which includes social networks, cultural traditions and activities that provide food and income, to be sufficiently flexible so that no adverse impacts of climate change are discernable on the social system. Such enabling conditions would clearly facilitate a sustainable development process, but would also require overcoming factors that cause vulnerability to climate change.[33]

50. Climate change challenges the traditional assumption that past hydrological experience provides a good guide to future conditions. Those responsible for managing water resources globally are already exploring innovative adaptation strategies in an attempt reduce their vulnerability to the types of potential climate change impacts described. Existing assessments show that the need to adapt is greatest in primary sectors,

[32] Maraun D, Wetterhall F, Ireson AM, Chandler RE, Kendon EJ, Widmann M, Brienen S, Rust HW, Sauter T, Themessl M, Venema VKC, Chun KP, Goodess CM, Jones RG, Onof C, Vrac M, Thiele-Eich, I. 2010. Precipitation downscaling under climate change: recent developments to bridge the gap between dynamical models and the end user. *Reviews of Geophysics*. Volume 48.

[33] Schipper L. 2007. *Climate Change Adaptation and Development: Exploring the Linkages*. Tyndall Centre for Climate Change Research. Working paper 107. Available at <http://www.unisdr.org/files/7782_twp107.pdf>.

like water resources, but do not show a clear prioritization for either "hard" or "soft" measures, or for vulnerability- or impact-focused adaptation.

51. Bates et al. propose that integrated water resources management (IWRM) provides an important framework to achieve adaptation measures across socio-economic, environmental and administrative systems and also that to be effective, integrated approaches must occur at the appropriate scales. This section reports on both water adaptation options that have been proposed and implemented as well as on the processes that led to the identification of these actions.

A. The UNFCCC context

52. Commitments of Parties to the Convention[34] (Article 4) include the need to cooperate and implement adaptation actions to address the impacts of climate change, with a particular focus on the needs of developing countries. Article 4, paragraph 1(e), of the Convention commits Parties to "develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods".

53. Information on adaptation activities relating to freshwater issues is mainly included in the NAPAs under the LDC work programme, national communications and the Nairobi work programme.

54. At its sixteenth session, the Conference of the Parties (COP), by its decision 1/CP.16, agreed to establish the Cancun Adaptation Framework, with the objective of enhancing action on adaptation, including through international cooperation and coherent consideration of matters relating to adaptation under the Convention. The framework reiterates the importance of strengthening, consolidating and enhancing the sharing of relevant information, knowledge, experiences and good practices, at the local, national, regional and international levels, to take into account, where appropriate, traditional knowledge and practices to promote enhanced action on adaptation. Decision 1/CP.16, paragraph 14(a), makes specific reference to water resources, freshwater, marine ecosystems and coastal zones in the context of "planning, prioritizing and implementing adaptation actions, including projects and programmes".

2. Examples of projects related to water resources under national adaptation programmes of action

55. The LDC work programme, established by the COP at its seventh session, includes the preparation and implementation of NAPAs. It provides a process for LDCs to identify and prioritize actions to respond to their urgent and immediate needs with regard to adaptation to climate change. Based on the NAPAs submitted as at September 2011, of the 485 projects identified, 74 priority projects relate to water resources. This number, however, does not include the priority projects developed under other vulnerable sectors such as agriculture and biodiversity, which also have components that have relevance to the water sector.

56. The NAPA priorities database[35] lists the ranked priority adaptation activities and projects, by country and sector. Typical priority activities of NAPAs in the water sector include: protecting water infrastructure, improving management of surface water, constructing storage facilities, rainwater harvesting, improving watershed management and monitoring, and raising community awareness. In agriculture, forestry and fisheries, a

[34] For the complete text of the Convention, see <http://unfccc.int/2853>.
[35] <http://unfccc.int/ 4751>.

relevant priority is promoting agricultural techniques and irrigation methods to fight soil salinity. A cursory review of the projects listed in the NAPA database yielded a list of possible adaptation actions as shown in Box 3.

57. A United Nations Development Programme dialogue paper analyzed national water policies and NAPAs. The paper suggests that one of the most important outcomes of the NAPA process was in terms of raising awareness about and building capacity to respond to a changing climate.[36] Even though the current scope of the NAPA guidelines does not allow for the provision of a long-term adaptation strategy or require implementation plans for proposed projects and strategies, NAPAs have succeeded in building capacity, including institutional capacity, among the sectors and ministries involved in the process.

58. Under the Cancun Adaptation Framework, a process was established to enable least developed country Parties to formulate and implement national adaptation plans, and for other developing countries to employ the modalities formulated to support these plans. This process will build upon their experience in preparing and implementing national adaptation programmes of action, as a means of identifying medium- and long-term adaptation needs and developing and implementing strategies and programmes to address those needs.

Box 3

Examples of water-related adaptation projects from submitted national adaptation programmes of action

Cross-sectoral:

- Implementation of a forecasting system for early warning and climatic risks for food security;
- Promoting the use of meteorological information to improve agricultural production and contribute to food security;
- Enhancing resilience to increasing rainfall variability through rangeland rehabilitation and rainwater harvesting.

Food security:

- Promotion of research on drought, flood and saline tolerant varieties of crops to facilitate adaptation in future;
- Securing cereal production through the promotion of supplemental irrigation;
- Rehabilitation of hydro-agricultural system of plains and lowlands;
- Building and enhancing adaptive capacity of vulnerable communities through improved access to services related to agricultural development.

Early warning systems and disaster management:

- Improvement of the quality of seasonal forecasts for rainfall and surface water flow;
- Establishing early warning system for flood-prone areas and improving and expanding meteorological and hydrological networks and weather monitoring systems.

Health:

- Prevention of water-borne diseases and other seasonal pathologies in rural areas;
- Provision of safe water in high-risk malaria regions;
- Improving the health status of the population by the prevention and management of vector-borne diseases caused by changes in temperature and flooding due to extreme rainfall.

[36] United Nations Development Programme. 2008. *Water Adaptation in National Adaptation Programmes for Action*. Paris: United Nations Educational, Scientific and Cultural Organization.

Water resources:

- Improved water management and use efficiency;
- Exploitation of surface water as a means to adapt to climate change in the most vulnerable areas;
- Rainwater harvesting and valorization;
- Stabilization of river dynamics of watercourses and torrents;
- Development and improvement of community irrigation systems.

Infrastructure:

- Rehabilitation of multiple-use dams; development and rehabilitation of flood protection dykes;
- Promoting protection measures adapted to the water supply infrastructures;
- Promoting the restoration and integrated management of small-scale hydraulic infrastructures such as multiple-use small-scale dams, artificial lakes and improved wells, establishing potable surface water.

59. It is also worth noting that single project or national-scale plans might not be able to capture the interlocked spatial and institutional scales that characterize the management of water resources.

3. Measures reported in national communications under the Convention

60. All Parties to the Convention report on the steps they have taken to implement the Convention (pursuant to Article 4, paragraph 1, and Article 12). National communications reported by both Annex I Parties and non-Annex I Parties provide information on, among other things, vulnerability assessment, climate change impacts and adaptation measures, including those relating to water resources.[37]

61. A number of anticipatory and reactive adaptation measures were identified in national communications submitted by non-Annex I Parties, mostly related to crop management, land management and soil and water conservation in agriculture and food security, for example: supply-side and demand-side management of water resources; conservation and management of forests and other terrestrial ecosystems; land-use planning and zoning and integrated coastal zone management; improvements in living standards; and surveillance, monitoring and early warning systems for outbreaks of disease vectors that threaten human health.

62. Adaptation measures reported in Annex I Parties in their national communications include restoring river systems (e.g. undertaking forest reclamation activities on river beds), supporting healthy rivers (e.g. desalination and distribution of potable water), applying sustainable harvesting methods and carrying out flood control measures. The systematic collection of data, monitoring and warning activities (e.g. development of warning systems in relation to water-related risks, monitoring of bodies of water and water availability) are under way in the water sector and many Parties have established institutions to support these activities.

4. Lessons learned from activities under the Nairobi work programme to date

63. Several Nairobi work programme partner organizations have pledged actions to: undertake research and assessment; enhance technical and institutional capacities; promote awareness; and implement adaptive actions on the ground. These actions have contributed

[37] Information on national communications from Annex-I Parties is available at <http://unfccc.int/1095> and on national communications from non-Annex I Parties at <http://unfccc.int/2716>.

to the enhancement of understanding and assessment of vulnerabilities and adaptation practices in the water sector.[38]

64. Although not developed to exclusively target specific vulnerable sectors, knowledge products, such as the adaptation practices interface[39] and the local coping strategies database,[40] provide information on adaptation planning and practices on vulnerable sectors at various levels of implementation.

65. The findings in a synthesis document of adaptation actions undertaken by Nairobi work programme partner organizations on freshwater resources[41] were organized into four areas: (1) research and assessment, (2) policy support, (3) raising awareness and capacity-building, and (4) adaptive actions on the ground. Some of the most important recommendations include:

(a) Building capacity in the local communities and involving community leaders and members to foster local ownership will help to ensure the continuity of implementation on the ground;

(b) Improving existing infrastructure could provide better water management solutions, and could prove more cost-effective and lead to increased efficiency of water management when compared with the results of building new infrastructure;

(c) Informed policy decisions can be made only with appropriate and context-specific data;

(d) Gaining a better understanding of current water resources is useful in defining actions to improve water security and adaptation;

(e) Strategic and methodological guidance documents are useful tools that can be utilized by decision makers to aid in the formulation of policy;

(f) At the national and regional levels, 'water dialogues' and forums are an effective means for communicating the climate change related issues to policymakers;

(g) The creation and dissemination of tools targeted at increasing the capacity of communities and policymakers in terms of climate change adaptation has been effective;

(h) Strategic collaboration and partnership among multiple stakeholders, including national and local institutions, regional authorities and academia are crucial in addressing adaptation issues for transboundary water bodies;

(i) Experiences from local initiatives can reveal approaches which incorporate cross-cutting adaptation measures.

66. Many actions undertaken by Nairobi work programme partners have contributed to a knowledge base of best practices. Although the effectiveness and success of any adaptation action is locally and socio-economically dependent, these good practices could be shared, replicated or scaled up. The ranges of adaptive actions on the ground reported in the synthesis document include practices that:

(a) Improve the resilience of ecosystems (such as reforestation activities and payment for ecosystem services);

[38] Information on action pledges made by Nairobi work programme partner organizations is available at <http://unfccc.int/5005>.

[39] <http://unfccc.int/4555>.

[40] <http://maindb.unfccc.int/public/adaptation>.

[41] See the UNFCCC publication *Climate Change and Freshwater Resources: a Synthesis of Adaptation Actions Undertaken by Nairobi Work Programme Partner Organizations.* Available at <http://unfccc.int/ 4628>.

(b) Change behaviour regarding the usage of water and addressing conflict situations;

(c) Build and restore physical infrastructure (such as dykes, water storage technologies, traditional springs and rain gauges);

(d) Diversify livelihood strategies (such as the use of microcredit tools and technologies developed using local resources);

(e) Revise laws and regulations (integration into national plans);

(f) Collect, analyse and disseminate information on local coping strategies to reduce vulnerability due to climate change impacts on freshwater resources.

67. From NAPAs to national communications, and even to some extent national planning exercises, it is challenging to assess on-the-ground success in freshwater-related adaptation efforts. National policies need to be informed by bottom-up lessons learned, while also creating an enabling environment for local and community-based adaptation actions to flourish.

68. The UNFCCC Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change, including on water resources, provides various methodologies for assessments of impacts and vulnerability, and preparing for adaptation to climate change.[42]

B. Regional, national and local initiatives

1. Regional and national climate change strategies

69. Adaptation plans and actions vary from community-based and utility adaptation plans to national and regional climate change strategies and plans of action. The outcomes and experiences are country-specific, and often have aimed to improve the process through lessons learned from leaders in the field. Countries can benefit, in particular, from drawing on the experiences and the best practices of countries with similar socio-economic, demographic, climatological, and hydrological characteristics that have already begun to address climate change impacts.

70. Good practices for planning and implementation were identified at all levels. At a regional level the European Union (EU) in its Water Framework Directive has established a comprehensive framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. The framework incorporates adaptation in a number of ways: it seeks to reduce the effects of droughts and floods; it allows for periodic reviews of climate change related pressures on European water resources; and it employs economic instruments aimed at using water more efficiently. With regard to adapting to increasing salinity, Egypt has advanced in promoting rice planting in saline areas. An example from Turkey shows that adaptation to reduced water availability can be successfully achieved at the household level by adjusting the demand for water. [43]

71. Countries are incorporating climate change dimensions into existing water management strategies and/or developing adaptation strategies (where often there were none before) that explicitly take into account climate risks. Countries have very different physical characteristics and are at very different stages in economic and social development, and, just as appropriate adaptation strategies need to be grounded in local contexts, water plans need to be tailored to the individual circumstances of the country and

[42] <http://unfccc.int/5457>.
[43] FCCC/SBSTA/2007/15.

local region. As climate change pressure mounts, traditionally fragmented and sectoral approaches are proving ineffective.

72. For example, in 2009, the World Resources Institute (WRI) reviewed the national climate change strategies of five developing countries: India, Brazil, China, Mexico and South Africa.[44] Some of these national climate change strategies are replicated in table 1. WRI analyzed the strategy development process, and proposed mitigation and adaptation interventions, and offered observations on adaptation interventions. While the national strategies on climate change reflect needs and priorities, WRI points out that national strategies serve best as guiding strategies under which, in sectoral or regional planning documents, countries would need to articulate in-depth specific action steps and implementation strategies.

73. Given the cross-cutting nature of water resources, a holistic management approach is essential. IWRM offers a way forward for sustainable management of limited water resources (at least in theory, although the practice is often less than robust); it also offers a framework through which countries can incorporate climate change impacts and vulnerabilities, and introduce adaptation strategies.

74. Motivated by the Dublin Statement on Water and Sustainable Development, which emerged from the 1992 International Conference on Water and the Environment,[45] IWRM is described as a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment.[46] With this guidance, organizations around the world seek to implement IWRM that is holistic, emphasizes effective institutions and is inherently adaptive in its design.

75. UN-Water[47] conducted a survey of developed and developing countries to assess the extent to which countries have been able to go beyond simply having IWRM plans in place to the stage of implementing those plans, and the extent to which tangible outcomes have been forthcoming. Through various survey instruments, and given data and developing country response limitations, the study still found indicators that IWRM approach is being incorporated into national plans and strategies.

[44] Fransen T, Nakhooda S, Chu E and McGray H. 2009. *Comparative Analysis of National Climate Change Strategies in Developing Countries.* Working Paper.World Resources Institute.

[45] Key principles of the Dublin Statement include: (i) fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment; (ii) water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels; (iii) women play a central part in the provision, management and safeguarding of water; and (iv) water has an economic value in all its competing uses and should be recognized as an economic good.

[46] Global Water Partnership Technical Advisory Committee 2000. *Integrated Water Resources Management*. Background paper no. 4. Stockholm: Global Water Partnership.

[47] UN-Water. 2008. *Status Report on Integrated Water Resources Management and Water Efficiency Plans*. Prepared for the 16th session of the Commission on Sustainable Development. Available at <http://www.unwater.org/downloads/UNW_Status_Report_IWRM.pdf>.

Table 1
Adaptation interventions proposed by three developing countries as shown in the World Resources Institute Comparative Analysis of National Climate Change Strategies in Developing Countries.[a]

India	*Brazil*	*Mexico*
National Action Plan on Climate Change	*National Plan on Climate Change*	*Special Program on Climate Change*
Agriculture • Drought/thermal/pest-resistant crop development • Improve communication and capacity of extension workers to support vulnerability-reducing activities • Weather modelling, risk insurance, credit; improve access to weather and agricultural information *Ecosystem/biodiversity* • Monitor Himalayan glaciers and ecosystems • Improve land use and development planning • Improve coastal protection through infrastructure and forest/mangrove restoration *Water* • Increase water use efficiency and equity • Mandate water harvesting and recycling • Wetlands conservation • Desalination technology development *General* • Support climate change research and modelling	*General* • Improve regional modelling of climate change impacts • Vulnerability mapping for coastal zones, biodiversity, water resources, electricity generation, oil and gas, desertification, urban areas • Reduce poverty and inequality • Prepare for health implications; improve knowledge base, increase technological capacity of health professionals, establish early warning systems • Identify most vulnerable groups and address socio-economic factors	*Agriculture* • Reduce soil degradation • Modernize hydro-agricultural infrastructure • Databases containing data on resilience of key crops *Ecosystems/biodiversity* • Preserve, widen, and connect protected areas • Build ecosystem resilience • Avoid and control spread of invasive species, diseases, parasites *General* • Evaluate current national capacities and seek sectoral integration • Deepen understanding of impacts of climate change on agriculture, forestry, water, ecosystems, infrastructure, cities • Payments for environmental services • Implement early warning systems • Promote climate-resilient building standards • Promote decentralized, small-scale, local energy supply systems

[a] Available at <http://pdf.wri.org/working_papers/developing_country_actions_table.pdf>.

76. Björklund et al.[48] concluded that, among LDCs, only Bhutan has fully integrated adaptation into national water policy. Member countries of the Nile Basin Initiative and the

[48] Björklund G, Tropp H, Harlin J, Morrison A. 2008. Water Adaptation in National Adaptation

Zambezi River Authority have begun to discuss water-specific adaptation issues within the context of the international river basin management framework.

77. While developing countries are more vulnerable and often the least capable of financing and developing adaptation plans, they are not the only countries at risk. Many developed countries have started to develop national approaches to understanding and managing climate risks to water systems. Countries such as the Netherlands, Spain, Australia and many others have an advantage in their ability to self-fund necessary adaptation actions. These countries have employed both soft (policy, instructional, communication) and hard (infrastructure, technology) strategies in response to climate change.

78. Australia has acknowledged that it will face major challenges due to climate change, climate variability and reduced water availability. For example, Water for the Future is the Australian Government's long-term initiative to better balance the water needs of communities, farmers and the environment.[49] Other countries will need to integrate adaptation to climate-change into the planning strategy of the different socio-economic sectors and ecological systems. It is important to employ both approaches, top-down and bottom-up, but in a coordinated manner.

2. Bottom-up adaptation approaches: ecosystem and community-based adaptation

79. Bates et al.[50] assert that adaptation to changes in water availability and quality will have to be made, not only by the water management agencies but also by individual users of the water environment, including industry, farmers (especially irrigators) and individual consumers. Adaptation actions in response to climate change depend on local conditions of vulnerability. Some actions are driven by indigenous knowledge, while some are integrated into a multisectoral approach to adaptation such as ecosystem-based adaptation. Box 4 lists some examples of local coping strategies related to freshwater resources.

80. Community-based adaptation (CBA) can be considered as an additional layer of community-based development activities, practices, research and policies. The hope is that experiences and knowledge learned on the plethora of pilot activities undertaken at the community level will be shared among the practitioners, policymakers, researchers, funders and the communities at risk. The International Institute for Environment and Development CBA Network and annual CBA conference offer forums through which CBA actors are engaging with and learning from each other (see an example in box 5).

81. There are some cases where top-down processes can facilitate bottom-up adaptation. A helpful example is the case presented in box 6, where the Adaptation Fund is mobilized to help implement adaptation actions aimed at reducing local vulnerability while building national institutional capacity to respond to climate change across relevant ministries.

Box 4
Local strategies to cope with freshwater stress

Reactive adaptation to rain shortages:

- Rescheduling agricultural timetables (late sowing, short cycle crops, several repeated sowings, dry sowing);
- Simultaneous practice of rain-based and irrigated farming;
- Changing farming practices away from crops associated with rain-based farming and

Programmers for Action. *The United Nations World Water Assessment Programme Dialogue Paper.* The United Nations Development Programme.

[49] <http://www.environment.gov.au/water/australia/index.html>.

[50] As footnote 2 above.

increasing the use of other farming practices (common among cattle rearers).

Measures designed to improve efficiency and effectiveness in water management for agricultural purposes:

- Using compartments, filtering dykes and growing vetiver;
- Creating artificial ponds;
- Dividing plots up using rows of stones to minimize runoff after torrential rainfall to encourage water infiltration and percolation;
- Dividing fields into rectangular plots with mounds of earth through which a canal network can be organized using pipes;
- Adopting new transplanting techniques to make best use of water;
- Placing pumps in holes to reduce pumping height at well installations;
- Conserving traditional water sources;
- Increasing the number of deeper wells.

Short-term adaptation to flooding:

- Corralling animals in family enclosures during high waters or flooding;
- Digging channels to drain stagnant water in the event of flooding;
- Digging ditches to collect flood and runoff water;
- Moving people to high ground in the event of flooding.

Measures used for the collection and storage of water for domestic use:

- Water stored in small plastic bottles in own grounds;
- Collecting rainwater from roofs of houses.

Other spontaneous and reactive adaptations:

- Use of alternative foodstuffs;
- Reduction of livestock during dry periods;
- Diversification and seeking of new occupations – fishing, raising cattle and so on;
- Traditional rationalization of fisheries;
- Moving to less dry areas; increasing migration;
- Change in stock size and herd composition;
- Changing roles of women and redistribution of household responsibilities;
- Fixation (nomads settling near water sources);
- Alternative food security measures and eating unconventional food items.

Further information

<http://www.nlcap.net/no_cache/news-single-view/article/17/18/>;
<http://www.wwfnepal.org>;
<http://tilz.tearfund.org/Research/Water+and+Sanitation+reports/Separate+streams+Adapting+water+resources+management+to+climate+change.htm>.

Source: UNFCCC, 2011. *Climate Change and Freshwater Resources: a Synthesis of Adaptation Actions Undertaken by Nairobi Work Programme Partner Organizations*. UNFCCC Secretariat. Bonn, Germany

Box 5

International Institute for Environment and Development (IIED) community-based adaptation case study in Cavite City, the Philippines

Cavite City is surrounded by three bays and so is at risk from rising sea levels and tropical cyclones. Other threats linked to climate change include erosion, sedimentation, flooding and saltwater intrusion into groundwater. Poor people are most at risk because of their vulnerability to climatic events and social, economic, technological and institutional factors.

Many autonomous adaptation tactics have positive outcomes, but they are inadequate and not effectively integrated into local development plans. They include accommodating sea level rise by building houses on stilts; reinforcing the physical structure of houses; moving to safer places during crises; placing sandbags along the shorelines; and engaging in alternative income generating activities.

Some government strategies (relief assistance, resettlement, shoreline protection, etc.) have reduced the vulnerability of coastal households, but the measures are inadequate and costly.

Consultations revealed that communities feel that they have only poor to fair human, physical and financial capacities to face the threat of climate change. People expressed significant concern over climate risks, and proposed several adaptation strategies, many of which were non-structural, capacity-building measures. They include:

- Improved knowledge management, such as: community-based monitoring of changes in coastal areas for input into vulnerability and adaptation assessments; creation of community early warning systems; and documentation, sharing and promotion of traditional knowledge, skills and practices that enhance adaptation;
- Policy and institutional reforms, such as: developing an integrated coastal zone management plan that includes land and sea use zoning; alternate livelihood development and 'eco waste' management; and providing secure property rights and microfinance/insurance schemes that enhance the adaptive capacity of vulnerable groups;
- Capacity development through: raising awareness; participatory risk and adaptation assessment and planning; alternative livelihood development; and creating a multisectoral integrated coastal zone management body.

Source: Huq S and Reid H. 2007. *Community-Based Adaptation: A vital approach to the threat climate change poses to the poor*. An IIED Briefing. London: International Institute for Environment and Development. Available at <http://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/6228/A%20vital%20approach.pdf?sequence=1>.

Box 6

Case study: Center for International Forestry Research and Centralised activities performed by the teams of Centro Agronómico Tropical de Investigación y Eseñanza research leads to United Nations funded five-year adaptation project in Honduras

A four-year study by Center for International Forestry Research (CIFOR) and Centralised activities performed by the teams of Centro Agronómico Tropical de Investigación y Eseñanza (CATIE)[a] defines the impacts of climate change on tropical forests and the role that forests play in helping societies to adapt in three regions: West Africa, Central America and South-East Asia. The study aimed to inform national-level adaptation via vulnerability assessment on the subnational scale in terms of society and its dependence on forest ecosystems, while also linking to the private sector within the regions to begin mobilizing funds. The study helped to secure Adaptation Fund financing for Honduras and became one of the first projects to be financed via the Adaptation Fund. Approved in September 2010, the USD 5 million programme began implementation in early 2011 and will close in 2016.

Honduras is one of the countries hardest hit by extreme weather events, yet adaptation to climate change had not been mainstreamed into development actions and related policies. The Adaptation Fund project will increase resilience of the most vulnerable populations

via pilot activities that reduce the threat of water shortages for the poor populations while paying substantial attention to the role of forests within the water cycle, such as how they capture mist from the atmosphere and the negative impacts of deforestation. The project is designed with an acknowledgement of the cross-cutting nature of water, and it therefore includes incorporating climate change into the planning processes and investment decisions of key line ministries. Its three key objectives are as follows:

1. Improved institutional capacities and tools for mainstreaming adaptation to climate change through the regulation and application of the new Water Law and the National Plan Law, which calls for intersectoral and landscape approaches that internalize climate change concerns.
2. Existing water stress and projected increased water scarcity in Tegucigalpa and environs, as well as flash floods due to extreme events, addressed through a range of complementary measures that will serve to pilot responses to climate change impacts in both watershed and urban settings.
3. Targeted capacity-building and tools enable stakeholders at all levels to effectively respond to long-term climate change impacts.

[a] Nkem J, Santoso H, Idinoba M, Saborio J and Herawati H. 2009. *Tropical Forests and Climate Change Adaptation: Criteria and Indicators for Adaptive Management for Reduced Vulnerability and Long-Term Sustainability.* Final Technical Report. Available from: <http://www.cifor.org/trofcca/home/products/attachments/Final-Technical-Report.pdf>.

82. The International Union for Conservation of Nature (IUCN) and CARE International conducted climate change vulnerability assessments for water-focused projects in Ethiopia, Uganda, the United Republic of Tanzania and Kenya. These non-governmental organizations used a combination of climate change adaptation tools, more specifically CVCA and CRiSTAL. Community members identified climatic hazards and impacts, defined appropriate coping strategies, and then brainstormed alternative coping strategies and the resources needed to put these strategies into place.[51] [52] An important component of this approach is the acknowledgment that vulnerability differs within households and communities, based on roles (often related to gender), power and access to and control over resources. CVCA is also used in promoting the integration of climate change adaptation issues into the medium-term plans (2010–2015) for two districts in northern Ghana (box 7).

Box 7

Integrating climate change into district planning in Ghana

In Ghana, CARE is working with local communities to promote the integration of climate change adaptation issues into the medium-term plans (2010–2015) for two districts in northern Ghana – East Mamprusi and Bawku. Using the CVCA (Climate Vulnerability and Capacity Analysis) process, key vulnerability issues were identified in target communities, with a particular emphasis on vulnerable groups. The process demonstrated the impacts of climate change in the region, with floods, droughts and erratic rainfall identified as key issues facing target communities. The analysis also yielded information on the particular vulnerability of women, who are largely responsible for maintaining family well-being, are often left behind by male family members who migrate in search of work, and who have insecure access to important resources such as land. This analysis is

[51] Cross K. and Awuor C. 2010. Integrating community-based adaptation in water projects across East Africa. *In*: *Community Champions: Adapting to Climate Challenges*. London: International Institute for Environment and Development. Available at <http://pubs.iied.org/pdfs/10028IIED.pdf>.

[52] CARE International. 2010. *Community-Based Adaptation Toolkit*. Available at <http://www.careclimatechange.org/files/toolkit/CARE_CBA_Toolkit.pdf>.

being used as the basis for the development of Community Action Plans which identify the priority actions to reduce vulnerability to climate change.

The project is combining bottom-up and top-down approaches by strengthening communities' capacity to communicate their needs and priorities to decision makers while also working with district officials to promote participatory planning processes. The project is placing particular focus on ensuring that women play a leading role in local governance by promoting their engagement in area councils and community-based organizations, and by strengthening their capacity to advocate for women's rights.

The expected outcomes of the project are district plans that incorporate the climate change adaptation priorities of vulnerable people, and increased capacity to adopt a participatory approach to local governance. Promoting district-level action to reduce vulnerability, while addressing some of the systemic inequalities that increase vulnerability of women, will build adaptive capacity to address future climate impacts.

Source: CARE International. 2009. *Climate Vulnerability and Capacity Analysis Handbook.* Available from <https://docs.google.com/viewer?url=http%3A%2F%2Fwww.careclimatechange.org%2Ffiles%2Fadaptation%2FCARE_CVCAHandbook.pdf>.

83. Ecosystem-based adaptation revolves around sustainably managing, conserving and restoring ecosystems so that they continue to provide the services that allow people to adapt to climate change**.**[53] The ecosystem-based adaptation approaches are identified as a range of key local and landscape-scale responses for managing ecosystems to build resilience to the adverse impacts resulting from climate change.[54] [55] This approach integrates managing ecosystems and biodiversity into an overall strategy that reduces vulnerability, enhances resilience to climate and non-climate risks, and facilitates adaptation. A co-benefit of ecosystem-based adaptation is that it can also play an important part in mitigation, given the role that ecosystems have in regulating the carbon cycle. These interventions can be designed to create synergy between adaption and mitigation. Examples include restoring wetland functions to cope with flood management and risk, and restoring land cover (e.g. forests or vegetation cover in farmlands) to stabilize land and regulate water flows.

IV. Needs and future priorities

84. Following the review of the state of knowledge regarding the potential impacts of climate change on water resources (chapter II) and some efforts that have been undertaken to date on adaptation options, including potential adaptation actions and strategies (chapter III), this chapter brings out key needs and future priorities based on issues and gaps in current practices of water resources planning and decision-making for effective adaptation plans and policies.

85. Climate change poses a major conceptual challenge to water managers and water users as well as policymakers in general. In addition, the projected changes in water quality and quantity due to climate change are expected to have a significant impact on other areas

[53] IUCN. 2010. *Ecosystem-based Adaptation: a Natural Response to Climate Change*. Gland: IUCN. Available at < http://www.iucn.org/unfccc/events/2010_cancun/publications/?uPubsID=3944>.

[54] "Ecosystem-based adaptation: an approach for building resilience and reducing risk for local communities and ecosystems". A submission by IUCN to the Chair of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention. Available at <http://unfccc.int/resource/docs/2008/smsn/igo/029.pdf>.

[55] Chapin FS, Callaghan TV, Bergeron Y, Fukuda M, Johnstone JF, Juday G and Zimov SA. 2004. Global change and the boreal forest: thresholds, shifting states or gradual change? *Ambio*. 33(6): pp.361–365.

(e.g. agriculture, energy, human health, infrastructure). Thus, the appraisal of adaptation options needs to be conducted across multiple water-dependent sectors.[56]

86. IWRM could be used to explore adaptation measures to climate change. A fully integrated approach is not always needed but, rather, the appropriate scale of integration will depend on the extent to which it facilitates effective actions in response to specific needs.[57] Planning for adaptation should include good water resources planning, and good water resources planning should account for climate change impacts – few of the LDCs, at the time of producing their NAPAs, had any sort of formal water sector plan, and fewer still had an IWRM plan.

87. Without effective institutions and adaptive management practices, vulnerable countries will continue to experience adverse climate change impacts. This what is commonly referred to as an enabling environment. An enabling environment for effective adaptation across multiple scales of intervention suggests responsive, inclusive and equitable governance capable of promoting change at the local, community level as well as the provincial, national and regional levels and beyond. CARE International has produced three helpful summary tables of the kinds of activities at the (1) national level, (2) local government level, and (3) household and individual level. These activities fall under four key elements of CBA: (1) Promotion of climate-resilient livelihoods strategies; (2) Disaster risk reduction strategies to reduce the impact of hazards; (3) Capacity development for local civil society and governmental institutions; and (4) Advocacy, social mobilization and empowerment to address the underlying causes of vulnerability. These tables are combined and replicated in table 2.

Table 2
Creating an enabling environment for Community-based adaptation[a]

Elements of community-based adaptation	*CBA actions at national level*	*CBA actions at local government/community level*	*CBA actions at household or individual levels*
Promotion of climate-resilient livelihoods strategies	Preparation of climate data summary in user-friendly formats	Scaling down climate projections	Promotion of climate-resilient agricultural practices
			Support for diversification of livelihoods, including non-agricultural livelihoods strategies
	Dissemination of climate change information to sectoral actors	Review of local plans/policies using climate change ‘lens’	
		Training for local government and non-governmental organization extension workers on vulnerability analysis and adaptation	
	Review of national sectoral policies with climate ‘lens’		Capacity building to analyse risks

[56] As footnote 2 above.

[57] Moench M, Dixit A, Janakarajan S, Rathore MS and Mudrakartha S. 2003. *The Fluid Mosaic: Water Governance in the Context of Variability, Uncertainty and Change*. Kathmandu: Nepal Water Conservation Foundation.

	Integration of climate vulnerability issues into poverty reduction strategies and/or other development plans	Promotion of climate-resilient agricultural practices	Promotion of savings and building capacity to plan for risk management
		Support for income diversification, including non-agricultural livelihoods strategies	
	Support for planning for disaster risk management	Support for implementation of local disaster risk management plans	Establishment of food and seed banks in places safe from hazards
Disaster risk reduction strategies to reduce the impact of hazards	Capacity building of disaster risk management actors with regard to climate change	Facilitating establishment of locally appropriate early warning systems	Improvement of shelter to withstand hazards
	Support development of early warning systems	Capacity building of local government and community to respond to disasters	Strengthening access to early warnings
	Build government capacity to respond to disasters		Facilitating evacuation planning
	Mapping of climate change adaptation capacity among national institutions	Promotion of participatory planning processes at local levels	Protection of assets
Capacity development for local civil society and governmental institutions	Support roll-out of national policies at the regional and local levels	Capacity building of local institutions to analyse climate risks and plan for appropriate actions	Strengthening of social protection schemes
	Advocacy for inclusive and transparent decision-making on adaptation	Establishing mechanisms for communication of climate information	Facilitating access to financial services
			Building knowledge and skills on adaptation strategies Facilitating access to climate information
	Awareness raising of vulnerability of women and other marginalized groups to climate change	Supporting voices of women and other marginalized groups in local planning processes	Empowerment of women and other marginalized groups
Advocacy, social mobilization and empowerment to address the underlying causes of vulnerability	Strengthening of civil society involvement in planning for adaptation	Advocacy on access to and control over critical livelihoods resources in local policies	Promotion of equitable division of labour within households
	Advocacy support for rights of vulnerable people		Advocacy on rights to livelihoods resources

[a] CARE International. 2009. *Climate Vulnerability and Capacity Analysis Handbook.* Available at <https://docs.google.com/viewer?url=http%3A%2F%2Fwww.careclimatechange.org%2Ffiles%2Fadaptation%2FCARE_CVCAHandbook.pdf>.

88. There remains a need for capacity-building, for socio-economic and observational data tailored to water sector planners, and for better understanding of adaptation options. In terms of socio-economic data to support decisions on adaptation in the water sector, the assessment of the economic value of water lacks widely accepted methodologies and basic data. Knowing the value of water and impacts of pricing of water on different stakeholders can be an important piece of information to force changes in water resource management.[58]

89. Financing for adaptation is needed for institutional strengthening, capacity-building and physical infrastructure. Coordinated management efforts and basin-wide institutional support is needed to avoid maladaptation downstream (e.g. an upstream reservoir that augments local supply to the detriment of other users) when implementing project-focused initiatives that may help the specific community in which they are located.

90. Adaptation planning and decision-making pertaining to water resources under climate uncertainty requires making assumptions about the future beyond the actual management actions under consideration. How will water demands in various sectors change in the future? How will land use change within water resource areas? How much water will actually be available to manage? How will growth affect consumption? While there are variations in the manner in which these questions are answered, a fairly common approach is to use past events as a reference for what will happen in the future: estimate future water demands based on an analysis and extrapolation of recent observed socio-economic trends; apply a similar approach to the estimation of future land conditions; and use historical observations of key components of the water cycle (e.g. runoff, aquifer recharge) to approximate future water availability.

91. Several alternative approaches have been proposed to respond to water resource vulnerability risk assessment and adaptation planning:

(a) There is a need to find ways to identify non-stationary probabilistic models of relevant environmental variables and use the models to optimize water systems;[59]

(b) The measures should help hedge against errors in the estimation of future demand for and supply of water services by planning for increments into the future;[60]

(c) There is a need for a new research direction that focuses on the design of the water system to create innovations in adaptation strategies that enable water systems to respond dynamically to a changing world.[61]

92. A key goal must be to ensure that all stakeholders have knowledge of different approaches to adapt to climate change impacts and uncertainties. Various approaches, tools and frameworks could be used for formulating and implementing water resources adaptation strategies.

93. For some decisions (e.g. seasonal cropping choice, seasonal water allocations, infrastructure operations) good water management measures and tools that have emerged

[58] See: FCCC/SBSTA/2007/15.

[59] Milly P., J. Betancourt, M. Falkenmark, R. Hirsch, Z. Kundzewicx, D. Lettenmaier,. R. Stouffer. 2008. Stationarity is dead: Wither Water Management? *Science*. 319, pp. 573574.

[60] Rogers, P. 2008. Coping with global warming and climate change. Journal of Water Resources Planning and Management. pp. 203–204.

[61] Brown C. 2010. The end of reliability. *Journal of Water Resources Planning and Management*. 136(3): pp.143–145.

from half a century of experience in the practice of water resources management planning and decision-making could offer adequate adaptation strategies.

94. *Guidance on Water and Adaptation to Climate Change*,[62] produced under the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes, mentions the following in a chapter entitled "Adaptation strategies and measures":

"As a first step, ongoing and new policy measures for adaptation or water management in general should be addressed vis-à-vis their capability to cope with current and future climate variability and change and to reduce vulnerability. As a second step alternative adaptation measures should be described. Identifying and evaluating different adaptation measures implies searching for options with low social, economic and environmental consequences, taking into account the development objectives, decision-making process, stakeholder considerations and the resources available. Options may be explored through various methods ranging from systematic qualitative analysis, semi-quantitative analysis in order to compare different attributes or parameters, and full quantitative analysis of risks, costs and benefits."

95. For transboundary water resources it is important for adaptation planning and practices to take place at a regional or a water basin level. The engagement of transboundary communities is important for assessing the impacts of certain water policies; this could be achieved through regional river basin arrangements, such as the Nile Basin Initiative.[63, 64]

96. The XLRM framework[65] could provide a useful framework that create space for technological and sociological dialogues and for top-down and bottom-up thinking (box 8).

97. The application of XLRM could provide a structure from which guidelines for best practices can be synthesized, as done in the context of following guidance:

(a) *Guidance on Water and Adaptation to Climate Change* implicitly touches on each of the components of the XLRM framework: future climate variability and change (X – Exogenous factors); adaptation measures should be described (L – Policy levers); various methods such as qualitative analysis and full quantitative analysis (R – Relationships); and searching for options with low social, economic and environmental consequences (M – Measures). The narrative of the guidance document fits nicely within a framework that can be applied as part of the water management planning and decision-making process;

(b) A narrative guidance document on water resources adaptation measures to climate change by Sadoff and Muller[66] fits a similar pattern.

Box 8

The XLRM framework (with example notions from the water sector)

XLRM as applied in the water sector organizes the important elements of deeply uncertain decision analysis by grouping them into four different categories:

[62] UNECE. 2009. *Guidance on Water and Adaptation to Climate Change*. Available at: <http://www.unece.org/index.php?id=11658>.

[63] See: FCCC/SBSTA/2007/15.

[64] Information on Nile Basin Initiative is available at <http://www.nilebasin.org>.

[65] See: Lempert R J, Popper S W and Bankes S C. 2003. *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-term Policy Analysis.* Santa Monica: RAND.

[66] Sadoff C and Muller M. 2009. *Water Management, Water Security and Climate Change Adaptation: Early Impacts and Essential Responses*. Global Water Partnership Technical Committee Background Paper no. 14.

(a) Exogenous factors (X) are those that are largely outside of the control of actors in the water sector and are often uncertain or not completely understood (e.g. climate change and demographic growth patterns);

(b) Policy levers (L) are those actions that can be taken to alter the outcomes (maintaining current operations are considered to be the first in very long list of potential actions);

(c) Relationships (R) describe how the factors interact with one another and describe the final output. The relationships in this case are typically represented in models;

(d) Performance measures (M) are the metrics used to determine the success of various strategies under different scenarios. These can be standard metrics such as system reliability and cost, or non-market metrics that emerge from the stakeholder community.

Within the XLRM framework, the sociological dialogue shapes the identification of key uncertainties of concern to key actors as well as the definition of metrics of performance. The definition of management strategies can emerge from a bottom-up assessment of actions that could address current vulnerabilities or from a top-down response to potential water resource impacts of a changing climate. The development of models to describe key relationships between uncertainties, management options and performance relies on the technological dialogue.

Uncertainties (X)	Management strategies (L)
▪ Climatic conditions ▪ Hydrological response to climate conditions ▪ Demographic factors ▪ Institutional and regulatory environment	▪ Current management ▪ Near-term investments, programmes, pricing strategies ▪ Signposts that trigger management changes or new investments ▪ Deferred management changes and/or new investments
Models (R)	Outcomes (M)
▪ Climate models ▪ Climate downscaling methods ▪ Rainfall-runoff models ▪ Water system and management models ▪ Water quality models	▪ Water demand ▪ Supply reliability ▪ Water quality ▪ Environmental and recreational objectives ▪ Cost (to agency and customers)

98. Developed by UNDP on behalf of the Global Environment Facility, *Adaptation Policy Frameworks (APF) for Climate Change: Developing Strategies, Policies and Measures*[67] provides a structured approach to formulating and implementing adaptation strategies, policies and measures to ensure human development in the face of climate variability and change. The primary use of the APF is to guide studies, projects, planning and policy exercises toward the identification of appropriate adaptation strategies, policies and measures. The framework is comprised of five components:

(a) Component 1: Scoping and designing an adaptation project;

(b) Component 2: Assessing current vulnerability;

[67] Information on Adaptation Policy Frameworks for Climate Change is available at <http://www.undp.org/climatechange/adapt/apf.html#about>.

(c) Component 3: Assessing future climate risks;

(d) Component 4: Formulating an adaptation strategy; and

(e) Component 5: Continuing the adaptation process.

99. A document developed by Tearfund gives guidance on how climate resilience and adaptation can be integrated into national-level policy and programmatic planning in the water sector. It aims to be practical and pragmatic and is based on existing conditions in terms of areas such as knowledge, skills, capacity and observed climate change impacts and risks.[68]

100. Analytical approaches such as the one proposed by Wilby and Dessai[69] could be used for screening and appraising adaptation actions

V. Conclusions

101. The paper has identified a number of conclusions for consideration:

(a) Findings from global assessments of climate and hydrological change are not directly usable by decision makers at regional, national and subnational levels; new guidance on developing appropriate climate scenarios is needed. This might include efforts to develop scenarios downscaled to the level of managing water resources, but might also focus on methods to develop narrative climate scenarios based on perceptions of key climate vulnerabilities;

(b) As climate change adaptation is a complex multi-faceted challenge, better analytical tools are needed to integrate the various dimensions of the problem. To date, significant effort has been invested in developing tools to assess the links between climate and hydrology. These tools offer insights into how large-scale patterns of runoff might change in the future. Adaptation decisions are not made based on assessments of naturalized runoff but are instead derived from assessments of how human interactions with hydrology produce positive or negative outcomes for the economies and ecosystems upon which human communities depend. These aspects need to be better captured in the available analytical tools;

(c) As the formulation phase of planning for water adaptation to climate change requires the use of a participatory and holistic process, efforts towards the adoption of the principles of IWRM should be encouraged. While IWRM does not explicitly integrate climate change considerations into the planning process, the underlying principles of good resource management can facilitate a process whereby information required for adaptation to climate change, including data and records, can be elicited from key actors;

(d) As the impacts of individual water management actions can accumulate within a particular water system, basin planning, even if it covers multiple political jurisdictions, should be encouraged as adaptation to climate change is identified and implemented. Transboundary cooperation is both necessary and beneficial in adapting to climate change. When planning adaptation across boundaries, riparian countries should focus on preventing transboundary impacts, sharing benefits and risks in an equitable and reasonable manner and cooperating on the basis of equality and reciprocity. This will assist in avoiding actions that might be adaptive in one location and maladaptive elsewhere, potentially increasing the conflict over water management and allocation. Transboundary cooperation can broaden the knowledge base, enlarge the range of measures available for

[68] The guide can be downloaded from <http://tilz.tearfund.org/Research/Water+and+Sanitation+reports/Water+adaptation+guide.htm>.

[69] As footnote 30 above.

prevention, preparedness and recovery, and so help to find better and more cost-effective solutions;

(e) As the analytical approach that is likely to emerge for integrating climate change considerations into planning and decision-making is likely to differ from the currently established practice, educational programmes for young water professionals should already be presenting alternative planning paradigms. Even if new standard procedures for integrating climate change into water management planning and decision-making are not yet in place, young professionals should be aware of the challenges confronting the current approach so that they can engage in developing new approaches that they can bring with them as they begin their professional careers.