TEC BACKGROUND PAPERS NO. 14

Water Management, Water Security and Climate Change Adaptation: Early Impacts and Essential Responses

By CLAUDIA SADOFF and MIKE MULLER

Global Water Partnership
Technical Committee (TEC)

Global Water Partnership (GWP), established in 1996, is an international network open to all organisations involved in water resources management: developed and developing country government institutions, agencies of the United Nations, bi- and multilateral development banks, professional associations, research institutions, non-governmental organisations, and the private sector. GWP was created to foster Integrated Water Resources Management (IWRM), which aims to ensure the co-ordinated development and management of water, land, and related resources by maximising economic and social welfare without compromising the sustainability of vital environmental systems.

GWP promotes IWRM by creating fora at global, regional, and national levels, designed to support stakeholders in the practical implementation of IWRM. The Partnership's governance includes the Technical Committee (TEC), a group of internationally recognised professionals and scientists skilled in the different aspects of water management. This committee, whose members come from different regions of the world, provides technical support and advice to the other governance arms and to the Partnership as a whole. The TEC has been charged with developing an analytical framework of the water sector and proposing actions that will promote sustainable water resources management. The TEC maintains an open channel with the GWP Regional Water Partnerships (RWPs) around the world to facilitate application of IWRM regionally and nationally. The Chairs of these RWPs participate in the work of TEC.

Worldwide adoption and application of IWRM requires changing the way business is conducted by the international water resources community, particularly the way investments are made. To effect changes of this nature and scope, new ways to address the global, regional, and conceptual aspects and agendas of implementing actions are required.

This series, published by the GWP Secretariat in Stockholm has been created to disseminate the papers written and commissioned by the TEC to address the conceptual agenda. Issues and sub-issues with them, such as the understanding and definition of IWRM, water for food security, public-private partnerships, and water as an economic good have been addressed in these papers.

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ABSTRACT

Water is the primary medium through which climate change will impact people, ecosystems and economies. Water resources management should therefore be an early focus for adaptation to climate change. It does not hold all of the answers to adaptation; a broad range of responses will be needed. But water is both part of the problem and an important part of the solution. It is a good place to start.

Globally, the overall impacts of climate change on freshwater resources are expected to be negative. But there is much that is not yet well understood. While the link between increased temperatures and changes in rainfall has been modelled in detail, the same is not true for the effect on river flows and the recharge of underground waters. Specific challenges posed by the melting of snow and glaciers need to be better understood, as do impacts on water quality.

Actions to implement robust water management are adaption actions. Understanding the dynamics of current variability and future climate change as they affect water supply and demand across all water-using sectors, and enhanced capacity to respond to these dynamics enables better water resources management. This strengthens resilience to current climate challenges, while building capacity to adapt to future climate change.

Achieving and sustaining water security, broadly defined as harnessing water's productive potential and limiting its destructive potential, provides a focus for adaptation strategies and a framework for action. For countries that have not achieved water security, climate change will make it harder. For those who have enjoyed water security, it may prove hard to sustain. All are likely to need to channel additional resources to water resource management.

A focus on water security is a sound early adaptation strategy; delivering immediate benefits to vulnerable and underserved populations, thus advancing the Millennium Development Goals, while strengthening systems and capacity for longer-term climate risk management. Many societies will want to continue to invest in water management to move beyond water security and take fuller advantage of the economic, social and environmental benefits that can be derived from wiser water use.

A water secure world will need investment in the three I's: better and more accessible *Information*, stronger and more adaptable *Institutions*, and natural and man-made *Infrastructure* to store, transport and treat water. These needs

will manifest at all levels – in projects, communities, nations, river basins and globally. Balancing and sequencing a mix of 'soft' (institutional and capacity) and 'hard' (infrastructure) investment responses will be complex. Information, consultation and adaptive management will be essential.

Furthermore, tough trade-offs are likely to be unavoidable in balancing equity, environmental and economic priorities. Finding the right mix of the three I's (information, institutions and infrastructure) to achieve the desired balance between the three E's (equity, environment and economics), will be the 'art of adaptation' in water management.

Integrated water resource management (IWRM) offers an approach to manage these dynamics and a thread that runs through these levels of engagement. IWRM is the global good practice approach to water management: it recognizes the holistic nature of the water cycle and the importance of managing trade-offs within it; it emphasizes the importance of effective institutions; and it is inherently adaptive.

Financial resources will be needed to build this water secure world. Sound water management, which is a key to adaptation, is weakest in the poorest countries, which also suffer the greatest climate variability today and are predicted to face the greatest negative impacts of climate change. Significant investment will be needed in many of the poorest countries.

Investment in national water resources management capacity, institutions and infrastructure should therefore be a priority for mainstreaming adaptation finance. It is sustainable development financing that delivers adaptation benefits. Mainstreamed funding will help ensure that long term capacity is built and retained in the institutions that are going to have to cope with these unfolding changes, and it will lessen the proliferation of complex climate change financing vehicles and fragmented, project-focused initiatives.

In some transboundary basins the best adaption investments for any individual country may lie outside its borders, for example in basin-wide monitoring systems or investments in joint infrastructure and/or operating systems in a neighbouring country. To the extent that specialized adaptation funds are made available, they should go beyond single-country solutions to generate public goods and to promote cooperative transboundary river basin solutions where it is cost effective and in the best interest of all riparians.

Foreword

The Global Water Partnership's vision is of a water-secure world, in which communities' needs for social and economic development are met; they are protected from floods, droughts, and water-borne diseases; and environmental protection is effectively addressed. Its mission is to support the sustainable development and management of water resources at all levels.

As part of its 2009–2013 Strategy, which articulates the way in which GWP will pursue its vision and mission in the years ahead, the Partnership is actively seeking solutions for critical challenges to water security. One of these is undoubtedly climate change, which threatens to fundamentally change the availability of water and the characteristics of the water cycle in many parts of the world.

Accordingly, Water Management, Water Security and Climate Change Adaptation: Early impacts and Essential Responses *focuses on the ways in which climate change will affect water – and, more importantly, how better water management can contribute both to mitigation of climate change and adaptation to those of its effects which are already irreversible.*

Looking to the crucial 2009 COP-15 meeting in Copenhagen, and the actions that will follow, one key message is that water is a primary medium through which climate change will impact people, ecosystems and economies.

A broad range of responses will be needed, focused around building generic water resource management capacities. So a second key message is that new instruments of adaptation currently being developed should support this approach. Water Management, Water Security and Climate Change Adaptation: Early impacts and Essential Responses *is thus an important contribution towards the current debate about ways to deal with climate change and its consequences. While water resources management may not hold all of the answers, it should nevertheless be an early focus for adaptation to climate change.*

I am grateful to Claudia Sadoff for her leadership in preparing the paper with co-author Mike Muller and writer Sarah Carriger together with the members of the GWP-wide working group on IWRM and climate change and in particular Michael Scoullos, Vadim Sokolov and Humberto Peña who contributed regional case studies. While the paper has benefited greatly from discussions within the GWP Technical Committee, it reflects the opinions of its authors and not necessarily the Technical Committee or the GWP as a whole.

The paper is not intended to be comprehensive, but to focus on some immediate issues in a way that complements existing publications by partners and others.

I am confident that the paper will be a valuable tool in GWP's efforts to contribute to and advocate solutions to address the critical water security challenges posed by climate change.

Hartmut Bruehl, Interim Chair, Global Water Partnership Technical Committee

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1. WATER AND ADAPTATION: FRAMING THE ISSUE

Many of the anticipated impacts of climate change will operate through water. Changing rainfall and river flow patterns will affect all water users; increased uncertainty and shifting crop water requirements will threaten poor rainfed farmers in particular; intensification of droughts, floods, typhoons and monsoons will make many more people more vulnerable; while risks and uncertainties will proliferate around water-borne disease incidence, glacier melt, glacier lake outburst floods and sea-level rise.

Of particular concern is that these impacts of climate change are likely to fall predominantly on poorer communities who are least able to cope – both now and in the future. Although the exact nature and extent of impacts cannot be predicted with absolute certainty, the long-term nature of water resource management means that responses need to start now. Fortunately, better water resource management will also help to manage current climate variability and shocks, which are fundamental development issues in the world's poorest countries today.

1.1. Water is the primary medium for early climate change impacts

The challenges posed by global warming and related climate changes are increasingly better understood, and there is growing consensus on their likely scale. These are no longer merely potential threats but an inevitable reality according to the most recent comprehensive IPCC Report.[1]

It is therefore important to give just as much attention to dealing with the impacts of a rapidly changing climate (adaptation) as to measures which tackle the drivers of that change (mitigation). As the IPCC has said, 'irrespective of the scale of mitigation measures, adaptation measures are necessary.'[2] Emphasis needs to shift from a focus that targets primarily the mitigation of climate change to a more integrated approach that embraces both mitigation and adaptation.

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[1] IPCC, *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., (Cambridge, UK: Cambridge University Press, 2007).
[2] IPCC, *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, UK and New York, USA: Cambridge University Press, 2007).

The same IPCC report makes it clear that once climates begin to change water resources will be amongst the sectors most affected. This is not a new finding. It was first highlighted in the final statement of the scientific sessions of the Second World Climate Conference, held in 1990, which recognized that: 'Among the most important impacts of climate change will be its effects on the hydrologic cycle and on water management systems and, through these, on socio-economic systems.'[3]

Some of climate change's impacts will simply reflect water's role in all life. So rainfed agriculture will have to adapt to new patterns of rainfall. Health care systems will have to cope with shifts in the incidence of diseases, such as cholera and malaria, due to changes in ecologies. Infrastructures, including roads and buildings, and indeed the very structure of human settlements will have to be altered to accommodate changes in precipitation and river flow patterns.

Changes in climate will be amplified in the water environment. It is widely predicted that changes of only a few degrees Centigrade and the resultant changes in precipitation could see average river flows and water availability increase by 10 – 40% in some regions and decrease by 10 – 30% in others.

This 'leverage' effect through which small changes in temperatures are translated into large changes in river flows could have a major impact on the water supplies to growing urban communities as well as on the other infrastructure built to meet their needs for shelter and transport. It may also render many of the industries and much of the agriculture that supply and feed them highly vulnerable, if not unsustainable.

In addition, it is predicted that the world's climate will be characterized by more, and more intense, floods and periods of drought. The dangers of a more stormy world are more easily appreciated by the public than the dangers of changes in temperature and rainfall patterns, if only because they are transmitted through media images of death and destruction following events like the devastation of New Orleans by Hurricane Katrina in 2005 and the floods in Bangladesh in 2007 caused by Cyclone Sidr, which took 3400 lives and left nearly a million people homeless.

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[3] In UN General Assembly, 45 Session, Addendum to Report of the Secretary General, *Progress achieved in the implementation of resolution 44/207 on protection of the global climate for present and future generations of mankind,* 8, November 1990, p. 9.

Because climate change impacts are amplified in the water environment, there are also dangers that go beyond the immediate water sector. If the interaction between climate change and the water environment is not understood, strategies in other sectors to address climate change may actually aggravate problems and increase the vulnerability of communities and their environments to both natural and manmade calamities.

This has already been seen in the rush to increase biofuel production, which compounded water stress and hunger in many regions. Another example is the campaigns against the export of irrigated vegetables and flowers from Kenya because of the environmental damage caused by air freighters. These campaigns, in areas where commercial irrigation has efficiently harnessed water to generate jobs, threaten widespread unemployment, which could aggravate existing conflicts in these resource-poor rural communities.

On the other hand, efforts to solve water problems that do not take into account climate change can compound its negative impacts. Engineered approaches to flood protection may protect communities from 'normal' floods but can leave them highly vulnerable to catastrophic infrastructure failures, such as those seen in the 2008 Koshi floods in Nepal and India, which affected over 3 million people. It can also potentially aggravate flooding disasters in the more extreme events that are likely under most climate change scenarios, as was vividly demonstrated in the case of the 2005 New Orleans disaster where flood control measures on the Mississippi had gradually reduced the extent of wetlands that would have provided a protective buffer against Hurricane Katrina. And approaches to water scarcity, such as energy intensive desalination, may in turn aggravate climate change if applied on a large scale.

Water will therefore be at the heart of both the risks and responses to climate change adaptation. This is not to say that water management holds all of the answers; responses will be needed across many sectors. Water is an important part of the problem, and an important part of the solution.

1.2. Water security is a priority for adaptation, and for today

A focus on water security is a sound early adaptation strategy – delivering immediate benefits to vulnerable and underserved populations, thus advancing the Millennium Development Goals, while strengthening systems and capacity for longer-term climate risk management.

But what is meant by 'water security'? Very often it is seen as analogous to 'food security' and 'energy security', which are generally defined as reliable access to sufficient supplies.[4] Here we will focus on security of the water resource, and therefore use a broader definition that also captures the destructive aspects of water – many of which will likely be amplified by climate change.

Following Grey and Sadoff (2007), we define water security to be: 'the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks.'[5]

To achieve water security, investments will be needed in infrastructure to store and transport water, treat and reuse waste water as well as in robust institutions[6] and the information and capacity to predict, plan for and cope with climate variability. Such investments will help societies to adapt to long-term climate change and manage current climate variability and shocks – thus offering water security to the world's poorest people and countries.

Many societies will want to move beyond water security to take fuller advantage of the economic, social and environmental benefits that can be derived from wise water use. Achieving and sustaining water security in the face of climate change, and going beyond water security to enhance the contribution of water to economic and social well being, are core challenges of adaptation.

Where water security has not been achieved, climate change will compound the challenge of achieving it

There are many societies where water security has not yet been achieved. The failure of the rains, of the water resource, often exacerbates poverty and conflict in poor communities. The flip side of the coin, too much water in the form of floods, exposes the poor to potentially devastating economic and health risks.

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4 *The World Food Summit Plan of Action* (1996) defines food security in the following way, 'Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.' Rome: FAO http://www.fao.org/docrep/003/w3613e/w3613e00.HTM. It should also be noted that food security is to a large extent related to water security, although this link can be bypassed through food imports.

5 David Grey and Claudia W. Sadoff, 'Sink or Swim? Water Security for Growth and Development,' *Water Policy* 9, No. 6 (2007): 545- 571.

6 Institutions are here broadly defined to include not only formal organizations, but also governance systems, policies, regulations and incentives that influence water allocation, quality, rights and pricing, asset management and service delivery.

In countries such as Ethiopia (see Box 1), the livelihoods – and indeed the lives – of many rural people depend on the vagaries of rainfall. Prosperity and social progress slowly built up over many years can be wiped out in a few seasons of drought. The picture is similar in many other African countries, where, as has been convincingly demonstrated in Kenya and Zimbabwe as well as Ethiopia, the fate of entire national economies is closely correlated with good or bad rains. Similarly in the Sahel region, water shortages as the result of long droughts have exacerbated social conflicts.

The link between rainfall, prosperity and social harmony is well recognized in most societies, although seldom expressed as clearly as in the small Southern African country of Lesotho, where *Khotso! Pula! Nala!* (peace, rain and prosperity) is a traditional greeting and national motto. In nearby Botswana, *Pula!* means not just rain but implies 'luck, life and prosperity,' which is why rain during a marriage or other event is considered extremely propitious.

In Asia, Central America and the Caribbean, it is floods more often than droughts that have the most devastating impact on poor communities. From Vietnam and the Philippines to Honduras, Nicaragua and Cuba, the damage and flooding from hurricanes and typhoons, which bring too much rain, keeps people in poverty by wiping out assets and increasing economic vulnerability.

In lands accustomed to extremes, there have been a number of events that suggest changing conditions. As an example, the floods that paralysed the Indian city of Mumbai in 2005 were caused by nearly 1000mm of rain – more than most countries receive in a year – falling in just 24 hours. The threat is that incidents such as this, which was described as a 'once in a two thousand year flood,' will recur far more often in far more places – imposing costs that make poor people even poorer.

To the extent that floods and droughts become more extreme, difficult to predict and less tractable to deal with, climate change will make the achievement of water security more difficult.

Where water security has been achieved, climate change could undermine it by increasing or changing risks

Over the past decades, programs to achieve the provision of safe and reliable water supplies have focused on getting the institutional arrangements and finances right, since the technical infrastructure, while costly, is not unduly complex. Similarly, in many countries, farming communities have found a balance between their natural resource endowments and constraints and, using the opportunities that access to a wider world makes possible, have achieved reasonable livelihoods. Industries in developing countries have been established using hydroelectric power, which remains by far the largest source of renewable energy in today's world.

However, this water security could prove to be illusory if the water resource on which it is based should be undermined.

In this context climate change represents a serious threat. Water supplies in many countries are based on the assumption that the dams from which their water is taken will provide a certain yield. If the average rainfall declines or droughts last longer than expected, those assumptions will no longer be valid and domestic supplies may be at risk. Farmers and other large water users face similar threats. In countries from India and Nepal to Kenya and Uganda to Chile and Brazil, one of the more serious impacts of drought is on the availability of electricity since less rain means less water though the turbines that generate it (see Box 4).

The picture is not uniformly bleak however. There are parts of the world where it is predicted that additional rainfall will increase water availability – although other problems such as flooding and the spread of water related disease could temper these advantages.

Achieving and sustaining water security against a backdrop of climate change is the immediate challenge of adaptation

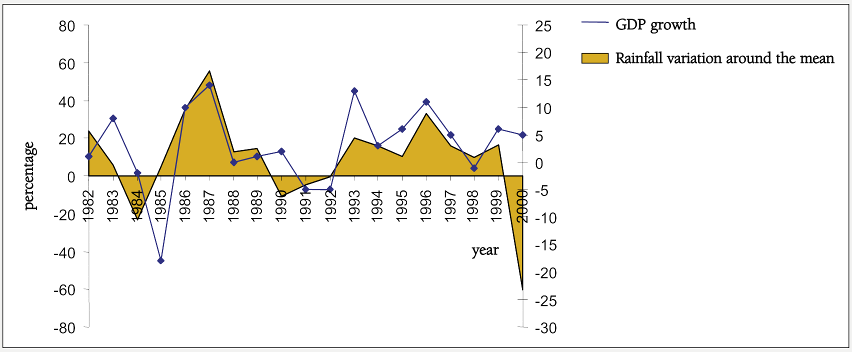
The achievement of water security is already a fundamental development challenge. Aside from the natural variability of the weather that drives the water cycle, there are many competing demands on what is, essentially, a fixed resource. These include growth in water demand due to increased requirements for industry, improved living standards, and changes in diets and in patterns of production (for instance, from the expansion of biofuel production). In many countries, pollution from disposal of human and industrial wastes is also reducing the amount of useable water.

Adding climate change to this potent mix increases the complexity of the challenges faced by water managers and their societies as they struggle to meet new demands. So the issue is not just to achieve water security in the face of climate change and all the other pressures that are coming to bear, but also to sustain it.

Box 1: The connection between rainfall variability and economic growth, the example of Ethiopia

Hydrological variability seriously undermines economic growth and perpetuates poverty in Ethiopia. The economic cost of hydrological variability is estimated at over one third of the nation's average annual growth potential, and these diminished growth rates are compounded over time. Economy-wide models incorporating hydrological variability show that projections of average annual GDP growth rates in Ethiopia drop by as much as 38% as a consequence of this variability.[7] Ethiopia has less than 1% of the reservoir water storage capacity per capita of North America to manage its much greater hydrological variability.

Figure 1: Ethiopia: Rainfall, GDP and Agricultural GDP



In Ethiopia, so sensitive is economic growth to hydrological variability that even a single drought event within a 12-year period (the historical average is every 3-5 years) will diminish average growth rates across the entire 12-year period by 10%. The effects of hydrological variability emanate from the direct impacts of rainfall on the landscape, agricultural output, water-intensive industry and power production.

Because Ethiopia lacks the water resources infrastructure and institutions to mitigate hydrological variability directly, and it lacks the market infrastructure that could mitigate the economic impacts of variability by facilitating agricultural trade between affected (deficit) and unaffected (surplus) regions of the country, impacts are amplified through input, price and income effects in the broader economy. The overall impact is that Ethiopia's economic growth is tied tightly to the rains (see Figure 1).[8]

Source: World Bank, Managing Water Resources to Maximize Sustainable Growth: A Country Water Resources Assistance Strategy for Ethiopia (Washington, DC: World Bank, 2006).

[7] The estimate is based on the results of a stochastic, economywide multi-market model that captures the impacts of both deficit and excess rainfall on agricultural and non-agricultural sectors.
[8] This graph presents a correlation that does not necessarily prove causality. An interesting question raised by this graph is why excessive rains are not associated with lower GDP growth. One possible explanation might be explored from the case of Kenya (see World Bank 2005). Here the majority of economic costs from drought are losses in agricultural incomes, whereas the economic costs of floods manifest in infrastructure damage (i.e., roads and bridges). In the calculation of GDP, agricultural losses directly diminish GDP. However infrastructure damage, if it were immediately repaired, could be recorded as investment in the national accounts, which would actually increase GDP and explain why excessive rains appear to be associated with strong growth.

1.3. Investments in water security are investments in adaptation

Just as climate change mitigation is being addressed through a series of fundamental changes in the way that societies produce and use their energy, adaptation will be addressed in part through a series of fundamental changes in the way societies manage and use their water (and land) resources.

Actions to implement robust water management are by nature adaption actions. Better water resources management means greater resilience today and more effective adaptation in the future. Actions will need to be guided by sound information, science and best practices from both the water and climate fields.

Given the complexity of the water cycle and the nature of the decisions that have to be made to manage it, information is essential and, even more so, the capacity to understand and apply it. In many countries, the capacity of both core water management institutions generally, and their information gathering functions more specifically, have come under pressure. Their ability to address current, let alone future, challenges is limited and urgently needs to be strengthened. Cuts in their budgets, most often made in response to short-term financial pressures, have left communities and countries more vulnerable in the longer term.

While many of the responses to water management challenges are as old as civilization, the new circumstances create many needs – and many opportunities – for innovation and fresh thinking. Practitioners and the public alike need to have access to the best possible information, including information on solutions developed by communities around the world, to ensure that they choose the most appropriate alternatives and are not trapped by the past into a dead-end future. More investment is needed in collecting and communicating information to support better decision-making by practitioners and the broader community of water users.

Strong institutions will be needed to gather, analyze and act on information

Water policies and practices must aim to build institutions, information and capacity to predict, plan for and cope with seasonal and inter-annual climate variability as a strategy to adapt to long-term climate change. To achieve the goals of water security and development, institutions are required that can engage water users and resource managers in an interactive way that enhances their ability to understand uncertainty, cope with it and respond to new challenges as they emerge.

The impacts of variability, aggravated by climate change, will be felt at different levels and have to be addressed at different levels. Individual farmers, commercial organizations, urban residents and national governments will all have to engage with the issues and take difficult decisions. Because decisions at all levels can affect the holistic resource, they will have to be coherent with one another if they are to be effective.

In this regard, it is important to establish effective, focused institutions to manage water, with governance structures that support the engagement of the different stakeholders in decision-making processes. These institutions should have links between the different levels of administration and, because water management impacts on so many other activities, they should be part of the broader business of government.

Investments will be needed in all three I's (information, institutions and infrastructure)

It is now widely recognized that engineering solutions, while vitally important and an integral part of any future approach to water management, will not by themselves be enough to solve the world's water problems. There is a range of social, economic and political challenges that have to be addressed and an equally wide range of hardware and software tools through which this can be done.

A water secure world will need investment across the three I's: better and more accessible *Information*, stronger and more adaptable *Institutions*, and natural and man-made *Infrastructure* to store, transport and treat water. These needs will manifest at all levels – in projects, communities, nations, river basins and globally. Balancing and sequencing a mix of 'soft' (institutional and capacity) and 'hard' (infrastructure) investment responses will be complex. Information, consultation and adaptive management will be essential.

At the same time, tough trade-offs are likely to be unavoidable in balancing the three E's: equity, environmental and economic priorities. This triple bottom line is an essential metric for sustainable development broadly, and water management more specifically.

The 'art of adaptation' in water management will be to find the right mix of the three I's (information, institutions and infrastructure) to achieve the desired balance between the three E's (equity, environment and economics).

Box 2: Investment decisions under climate change – Lesotho Highlands

A practical example of the challenges posed by climate change is the decision that had to be taken in South Africa about the source of the next major increment in water supply to the metropolitan area of Johannesburg and its surrounding industrial heartland. There were two main options:

- To expand the existing Lesotho Highlands Water Project, which would mean taking more water from the Orange River system, which rises in the mountains of Lesotho and flows to the Atlantic Ocean on the border with Namibia, and putting it into the Vaal system.
- To capture water from the other side of the divide, from the Thukela and other shorter, smaller rivers that flow to the Indian Ocean on the East Coast, and transfer it into the Vaal basin.

Both options are expensive, costing over a billion dollars and taking up to a decade to plan and build, so decisions could not be taken lightly. The comparative costs of the alternatives were not dissimilar.

Factors affecting the decision include differences in operating costs, since one solution required less pumping than the other, and political considerations, since the existing treaty between Lesotho and South Africa provides for further phasing of existing transfers, and a further phase would bring a substantial cash injection to Lesotho. Capital costs are, however, always an important determinant of the lifetime cost of water delivery, so the comparative costs of the alternatives were an important issue. But apparent differences in the unit cost of water calculated for each scheme would be meaningless if the hydrological forecasts on which they are based are not reliable or comparable.

Climate science offered only limited help in making this decision. It is currently suggested that for South Africa, in terms of rainfall, the west and south western parts will become drier, and the east of the country will stay the same and may even become wetter.

In this case, climate predictions suggested that it might be less risky to opt for an eastern river source, which is predicted to be less affected by climate change and would have the advantage of maintaining a balance between different sources – a more resilient system. But little weight could be given to these predictions since they were not consistent between different models and firm information about project costs had to be traded off against what is at present far less precise climate information. However, in the end, the decision to go with the Lesotho scheme was made for other climate-related reasons: The energy requirements to pump water from the eastern scheme were considered to be a major problem from a mitigation perspective.

According to the Department of Water Affairs and Forestry, the reasons for selecting the Lesotho Highlands option were as follows: 'the project has a low energy requirement in that water can be transferred under gravity to South Africa without pumping - unlike the Tugela option, which is energy intensive as water must be pumped from the Thukela River over the escarpment. Furthermore the existing hydropower generation capacity of the Lesotho Highlands Water Project Phase 1 can also be increased. The project would bring substantial benefits to Lesotho as well as a

Box 2: Investment decisions under climate change – Lesotho Highlands, cont.

regional benefit, as it will mean the prevention of increased carbon emissions' (Outcomes of Cabinet Discussion, 4 December 2008).

This example illustrates why many practitioners argue that it is not yet possible for water managers, in low-income countries in particular, to take climate change adaptation into account in their designs. Yet the logic remains that water investments should be designed to perform under future climate regimes. The present challenge is thus to improve the descriptions of those possible regimes by reducing the uncertainties that multiply at each step of the hydrological cycle – from temperature predictions to estimates of rainfall, evaporation, infiltration and runoff – to obtain reasonably reliable predictions of stream flow and groundwater availability. If these flows can be better predicted, they can better be managed.

Sources: Department of Water Affairs and Forestry, Outcomes of Cabinet Discussion on Water and Augmentation of the Vaal River System, Media release, 4 December 2008; Mike Muller, 'Adapting to climate change: Water management for urban resilience,' Environment and Urbanization 19, No. 1 (2007): 99-113.

2. CLIMATE CHANGE CHALLENGES FOR WATER MANAGEMENT

In order to understand the challenges that face us, it is necessary to look at climate change and its impacts through a variety of lenses – physical, social and economic. It is also helpful to consider some of the other pressures on the resource that are already stretching the coping capacity of many societies to the limit.

2.1. The physical science

There is general consensus that climate change will have significant negative impacts on the global freshwater cycle. The IPCC tells us:

> **Globally, the negative impacts of future climate change on freshwater systems are expected to outweigh the benefits** *(high confidence)*. By the 2050s, the area of land subject to increasing water stress due to climate change is projected to be more than double that with decreasing water stress. Areas in which runoff is projected to decline face a clear reduction in the value of the services provided by water resources. Increased annual runoff in some areas is projected to lead to increased total water supply. However, in many regions this benefit is likely to be counterbalanced by the negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality and flood risks *(high confidence)*.[9]

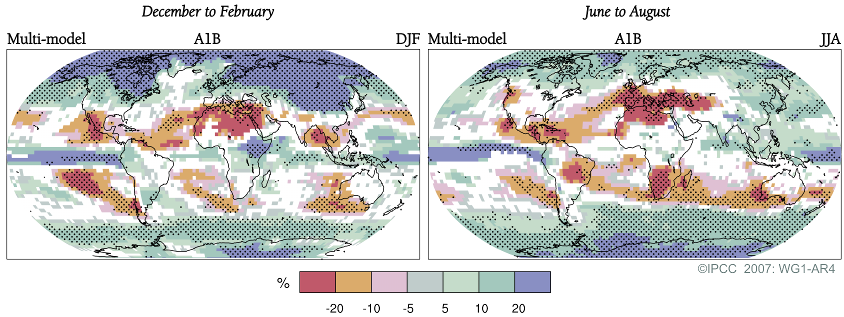
But the physical science relating climate changes to hydrology is not widely understood. Significant effort is needed to model and predict changes in the hydrological cycle that might result from climate change – not just at the global scale, but also at scales relevant to decision making. This section reviews some of the key technical issues, linking them to the most recent findings of the IPCC's Technical Team on water and climate.

Changing rainfall patterns

At present, rainfall predictions are still relatively general and are indicative rather than definitive (see Figure 2). Although regional predictions are being made with increasing degrees of precision, they are generally untested and can still only be used to describe the kinds of challenges that may arise. Similar caveats apply to the other key dimension of climate variability, the predictions that there will be more extreme events.

[9] Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change*, Geneva: IPCC Secretariat, p. 3.

Figure 2. Projected Patterns of Precipitation Changes



Percent changes in precipitation for the period 2090 – 2099 relative to 1980 – 1999. Values are multi-model averages based on the SRES A1B scenario. White areas are where less than 66% of the models agree in the signs of change and stippled areas are where more than 90% of the models agree.

Source: IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 16, Fig. SPM 7.

In April 2008, the technical team of the IPCC working on this issue could only say:

> **Climate model simulations for the 21st century are consistent in projecting precipitation increases in high latitudes** *(very likely)* and parts of the tropics, and decreases in some subtropical and lower mid-latitude regions *(likely)*. Outside these areas, the sign and magnitude of projected changes varies between models, leading to substantial uncertainty in precipitation projections. Thus projections of future precipitation changes are more robust for some regions than for others. Projections become less consistent between models as spatial scales decrease.[10]

Similarly, on the likelihood of extreme events, their summary conclusion was:

> **Increased precipitation intensity and variability is projected to increase the risks of flooding and drought in many areas.** The frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) will *very likely* increase over most areas during the 21st century, with consequences to the risk of rain-generated floods. At the same time, the proportion of

[10] Ibid.

> land surface in extreme drought at any one time is projected to increase *(likely)*, in addition to a tendency for drying in continental interiors during summer, especially in the subtropics, low and mid-latitudes.[11]

If it is difficult to make good predictions about the future of rainfall and storms, it is even more difficult to predict the impact of changing temperature and rainfall on water availability from rivers, lakes and underground sources.

While the amount and timing of rainfall is critically important to some water users, notably farmers, the majority of users draw their water either from surface water resources such as rivers or lakes, or from underground sources. These are fed by rainfall, but the relationship between the amount of rainfall and the amount of water available in rivers, lakes or underground is a complex one.

Runoff and streamflow

A reduction in runoff will be perhaps the most serious impact of global warming on the water environment. Rivers rise when rainfall 'runs off' the land or percolates into aquifers to emerge later as springs. Other things being equal, with the drier ground and increased evaporation of a hotter climate, less water will run off to the rivers or percolate into the deeper aquifers. This is why climate change is 'amplified' in the water cycle.

But the 'other things,' which include the types of vegetation as well as the timing and intensity of rainfall, are unlikely to remain equal. Vegetation will change as a result of changes in temperature, rainfall and CO_2 concentrations. The intensity and timing of rainfall will change as a consequence of the changing circulation patterns inherent in generalized atmospheric warming.

In some drier areas, notably in sub-Saharan Africa and the Mediterranean region but also in South Asia and Australia, reductions in stream flow of more than 50% are confidently predicted with many perennial streams becoming seasonal and others drying up permanently.[12] This change could have devastating impacts on human activities as well as bringing about permanent changes in ecosystems, including the extinction of many species.

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[11] Ibid.

[12] Maarten de Wit and Jacek Stankiewicz, 'Changes in Surface Water Supply Across Africa with Predicted Climate Change,' *Science* 311, No. 5769 (2006): 1917-1921; published online 1 March 2006 [DOI: 10.1126/science.1119929].

Figure 3. Projected changes in runoff by 2080 for Mexico and Central America

Mexico and Central America are predicted to experience a significant reduction in runoff. The resulting decrease in water availability will greatly affect the region's agriculture, with disproportionate impacts on poor rainfed farmers. Even large-scale irrigated areas, such as those in Mexico's breadbasket, will be affected.

Source: 'In search of shelter: mapping the effects of climate change on human migration' p. 7.

At the other extreme, more intense rainfall will saturate the ground faster than usual. If it continues to rain, more water will run off into streams and rivers and floods will be larger and more damaging.

These findings are summarized by the IPCC as follows:

> **By the middle of the 21st century, annual average river runoff and water availability are projected to increase as a result of climate change at high latitudes and in some wet tropical areas, and decrease over some dry regions at mid-latitudes and in the dry tropics.** Many semi-arid and arid areas (e.g., the Mediterranean basin, western USA, southern Africa and north-eastern Brazil) are particularly exposed to the impacts of climate change and are projected to suffer a decrease of water resources due to climate change *(high confidence)*.[13]

[13] *Climate Change and Water*, p 3.

Temperature, evaporation and aridity

As already indicated, one effect of temperature increases is to increase evaporation rates. Since the balance between evaporation and rainfall determines whether a climate is humid or arid, aridity will tend to increase where rising temperatures are not matched by rising rainfalls. A change in the timing and intensity of rainfall could also drive the transition from humidity to aridity. Changes in aridity will have a substantial impact on both surface water runoff and groundwater recharge.

Aridity is defined technically as the ratio between rainfall and potential evaporation. The relationship is best explained by the 'Budyko curve' which describes how the 'runoff' from a catchment depends on the balance between potential evaporation and rainfall. Potential evaporation is determined by the amount of energy in a catchment – usually sunshine. In humid climates, evaporation is less than the rainfall, ensuring that excess water 'runs off' into rivers and lakes or infiltrates into the ground. In arid climates, the potential evaporation exceeds the rainfall and actual evaporation depends on the amount of water available to be evaporated. Only in periods in which there is sufficient rainfall to 'swamp' the evaporation does runoff or infiltration to groundwater occur.

Understanding this relationship already provides a powerful tool to predict future changes, but it has its limitations. Critically, analyses have rarely taken into account changes in vegetation.

Changing groundwater recharge and storage

One of the most difficult water resource management challenges is monitoring and managing underground water, which many communities depend on for their water supply. Because it is essentially 'invisible,' its unsustainable use is often only recognized when pumps run dry. If the runoff from rainfall that flows into rivers and streams is affected by changes in temperature and land use, so too is the infiltration of water into underground formations.

In the temperate zones and the humid tropics, water often lies on the surface for days and weeks during rainy periods and is thus able to slowly seep down into the underlying aquifers. The situation in drier climates is much less predictable. In the warmer, more arid climates, where soils are often dry, the first rain that falls is absorbed by the top layers of soil; if a dry period follows, much of this moisture will be used by vegetation or evaporate back into the atmosphere. It is only when there is a relatively large amount of rainfall, concentrated over a period of a few days, that sufficient water can accumulate on the surface and upper layers of the soil, allowing the surplus to percolate into the underlying aquifer.

The intensity and duration of rainfall is thus critical in determining what proportion of rainfall will eventually contribute to the recharge of aquifers; the initial dryness of the soil and the nature of vegetation covering it are similarly related. All of these dimensions are expected to change under most climate change scenarios.

Water quality

The capacity of surface water resources to receive, dilute and remove human wastes is dependent on the volumes of water flowing in them. Any reductions in river flows will reduce their capacity to dilute wastes and additional investments will be required to achieve the same standards of environmental protection or to treat wastewater for reuse.

Changing runoff patterns and temperatures may result in water quality effects that either render water unusable (as in agriculture, where salinity is a major determinant of viability), or impose additional treatment costs on users (as in the case of the eutrophication of waters used for domestic supplies).

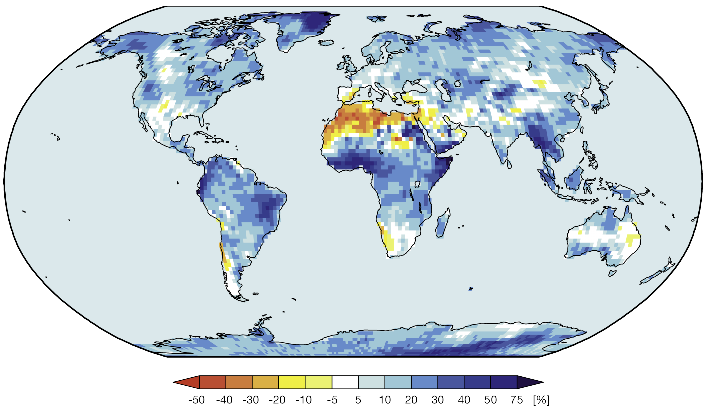
The intrusion of seawater into coastal freshwater systems is another possible consequence of climate change. And this will not just occur in areas affected by sea level rise but also where reduced river flows are insufficient to prevent seawater from flowing upstream. As estuaries and groundwater become increasingly saline, less freshwater will be available for human and ecosystem use in coastal areas.

Floods, droughts, and more intense and more frequent storms

One immediate and obvious impact of changing rainfall patterns will be the changing incidence of floods and droughts. Higher temperatures will lead to greater evaporation from the ocean and other sources, which will in turn create the potential for more, and more intense, rainfall. The effect of this will be that floods and droughts that are currently considered to be rare events will become more common, while new extremes will begin to occur.

Like many impacts of climate change, climate related disasters are disproportionately affecting the poor. The 2008 UN Human Development Report stated that from 2000 to 2004, some 262 million people were affected by climate-related disasters annually. Over 98 percent of them lived in the developing world.

Figure 4. Percentage changes in annual extreme precipitation under scenario A1B.



Annual extreme precipitation is defined here as the maximum amount of precipitation in a 5-day period in a given year. The figure shows the percentage change in the 30-year means for the period 2071–2100 relative to the means for 1961–1990.

Source: Andrew Thow and Mark de Blois, 'Climate change and human vulnerability: Mapping emerging trends and risk hotspots for humanitarian actors: Volume 2: Technical annex and additional maps.' p. 13. Copyright © 2008 Cooperative for Assistance and Relief Everywhere, Inc. (CARE). Used by Permission.

Glacier and snow melt and loss of storage

The shrinking of glaciers and reduction in the volume of water 'stored' in snowfields is one of the earliest impacts on water resources expected from climate change. Until recently, the role of snowfields and glaciers in 'smoothing' variability in precipitation was not widely recognized. The threat of climate change has however changed that.

These areas currently act as huge natural reservoirs, collecting and storing water as snow in winter and releasing it gradually as melt-water in summer. Under most global warming scenarios, the melting of snow and glaciers will first increase and then reduce river flows over the course of some decades, causing first floods, then droughts. There is also likely to be substantial erosion of newly exposed land surfaces, which will impact on water quality.

The water supply of one-sixth of the world's population is dependent upon glacier and snow melt.[14] Even more people are dependent upon melt-fed rivers for their water supplies, agricultural water, navigation and hydropower. The loss of glaciers is particularly important in the Andean region of South

[14] T. P. Barnett1, J. C. Adam & D. P. Lettenmaier, 'Potential impacts of a warming climate on water availability in snow-dominated regions,' *Nature* 438 (2005): 303-309.

America (see Box 3) and the western Himalayan region of South Asia. In the Andes, water supplies routinely depend directly on glacier and snow melt. Ecuador's capital, Quito, for example, draws 50% of its water supply from the Antizana and Cotopaxi glacier basins.[15] In the agriculturally rich Indus river basin, home to some 180 million people, up to 50% of the river flow is attributed to glacier melt.[16]

A related risk is what is known as glacier lake outburst floods, or GLOFs. As glaciers melt, they often form lakes that are held back by moraines – essentially earthen dams formed by the boulders and soil pushed ahead of advancing glacier. As glaciers retreat these lakes grow and their natural dams come under increasing pressure from the rising waters. The result can be unpredictable and catastrophic outburst floods. The International Center for Integrated Mountain Development (ICIMOD) has identified over two hundred glacial lakes in the Hindu-Kush-Himalaya mountain range that are at risk of outburst.[17]

Monitoring change – data and hydrology

Water resource managers need the ability to track changes and to devise and support the implementation of appropriate responses. This requires extensive data and the ability to analyze and interpret it in order to guide planning and inform the broader community of its implications.

Although the importance of hydrological monitoring has been highlighted at all United Nations conferences on water and sustainable development since the 1977 Mar del Plata conference, there has been a worldwide decline in the availability of water resources data over the past few decades. Indeed, evidence suggests that in many countries, the quality of the hydrological data has deteriorated sharply since the Rio Summit in 1992. Much of the global data on streamflows held by the Global Runoff Data Centre in Germany is more than 30 years old. In 2008, international support was terminated for the Global Environmental Monitoring System (GEMS) program, which was the worldwide repository of water quality data. Some funding has now been restored, but it is not enough.

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[15] W. Vergara, A. M. Deeb, A. M. Valencia, R. S. Bradley, B. Francou, A. Zarzar, A. Grünwaldt, and S. M. Haeussling, 'Economic Impacts of Rapid Glacier Retreat in the Andes,' *Eos Trans*. AGU 88, No. 25 (2007): doi:10.1029/2007EO250001.

[16] Mats Eriksson, Xu Jianchu, Arun Bhakta Shrestha, Ramesh Ananda Vaidya, Santosh Nepal, and Klas Sandström, 'The changing Himalayas – Impact of climate change on water resources and livelihoods in the Greater Himalayas.' Perspective Document for the 5th World Water Forum, Istanbul. Katmandu: ICIMOD (2009).

[17] ICIMOD, *Inventory of Glaciers, Glacial Lakes and Identification of Potential Glacial Lake Outburst Flood (GLOFs) Affected by Global Warming in the Mountains of Himalayan Region* (Kathmandu: ICIMOD, 2007). DVD/CD-ROM.

Box 3: The impacts of climate change on the Chilean-Argentine Andes

The Andes Mountain Range is of huge importance for the hydrological resources of both Argentina and Chile, since precipitation in its mountains represents up to 80% of the water availability of central Chile and Argentina's inland provinces.

These resources are of special interest for the central region of Chile and the oases of the Argentine west, in the regions of Cuyo and the north of the Patagonia. These areas, which have an arid or semiarid climate and a Mediterranean type rainfall regime, are home to highly productive irrigated agriculture – with 1,300,000 hectares in Chile and around 400,000 hectares in Argentina dependant on the spring and summer streams that are fed by snowmelt from the high points of the mountain range. The terrain also favours hydroelectric generation, and 4,000 MW of hydroelectric power have already been developed in Chile, and 750 MW in Argentina.

Global climate models consistently predict an increase in air temperatures and an aggravation of aridity conditions in these areas.[18] Because of the importance of water resources to the economic health of these areas, both countries have worked to develop more finely tuned climate prediction models that allow for a more realistic representation of the Andes's effect on a river basin scale.

The results of this research indicate that, by the end of the 21st century, the mountain range area may experience average temperature increases of up to 4°C and more variable precipitation with an average decrease of 15% on the eastern slope (Chile) and in the mountain zone, and an increase in the foothills of the western slope (Argentina).[19]

Due to the hydrological features of the area, the predicted increases in temperature would have greatly amplified impacts on water flows. Higher temperatures raise the snowline, decreasing the area that accumulates winter snow, and result in more precipitation falling as rain rather than snow. They also accelerate snow melting. Thus the winter and spring stream discharges will increase and the summer and autumn discharges will decrease.

A temperature increase of 3°C, even without any modification in rainfall, results in a predicted increase of up to 100% in winter monthly flows in some of central Chile's basins, and a decrease of about 30% in the summer months.[20] Simulations for the end of the 21st century that also factor in the predicated precipitation decrease show summer flows reduced by over 50%.[21] Compounding these dire predictions is the observed retreat of the area's glaciers.

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18 Secretaría de Medio Ambiente de la Nación (2009), *Cambio Climático en Argentina*; CONAMA-Chile, *Plan de Acción Nacional de Cambio Climático 2008-2012*.
19 PNUD-SECYT (1997). *Vulnerabilidad de los Oasis comprendidos entre 29°S y 38°S ante condiciones más secas en los Andes altos*. Proyecto ARG/95/G/31; Dpto. Geofísica (Universidad de Chile) – CONAMA (2006). *Estudio de las Variabilidad Climática en Chile*, para el Siglo XXI.
20 Humberto Peña (1987). *Sensibilidad del Régimen Hidrológico de la Cuenca del río Maipo frente a un cambio Climático*, 20th Congress of the Chilean Society of Hydraulic Engineering.
21 X.Vargas; E. Rubio, G. Mardones and D. Mena (2008). *Análisis del Stress Hídrico en Cuencas Chilenas por Efecto del Cambio Climático*, 10th Francisco Javier Dominguez Sessions, Chilean Society of Hydraulic Engineering.

Box 3: The impacts of climate change on the Chilean-Argentine Andes cont.

Greater temperatures imply an increase in plant evapotranspiration, which constitutes about 80% of total water demand, so this effect in combination with the changes in water availability have grave implications for the water security of the region, particularly in agriculture. Hydroelectric generation would not be as affected, since current electric demands are greater in the winter months, which are predicted to experience increased stream flows.

In addition to impacting water availability for different uses, higher temperatures would also increase risks of flooding. In Chile's case, this may seriously compromise the safety of major cities located just below the Andes. For example, take the country's capital, Santiago: if the temperature increase raises the snowline by 500 meters, as predicted in climate change scenarios for the end of the 21st century, the runoff area would be increased by a factor of three. The resulting discharges during floods would exceed the capacity of the current drainage system many times over.[22] Similarly, diverse activities and infrastructure in the mountain range area, such as dams, mine works, roads, hydroelectric plants, tourist facilities and others would be impacted.

Also, the change from a predominantly snow-based hydrology to a predominantly rain-based one profoundly alters the transportation of sediment and the whole geomorphologic dynamic of the basins, which in turn could drastically affect drainage systems and water control and storage structures.[23]

These and other challenges associated with climate change have motivated the Chilean and Argentine governments in recent years to create multi-sectoral collaborative groups to facilitate the study of climate change and formulate public policies for adaptation. In this context, different courses of action are proposed, such as developing monitoring and research programs, building dams and for better management of eventual seasonal changes of discharges, developing capacities to adapt crop patterns to the varying climate conditions and water availability, strengthening water resource management capacities in scenarios of scarcity, and adapting flood infrastructure. These possible courses of action are still being evaluated but should start to yield results in the next several years.

Author: Humberto Peña

[22] Humberto Peña (1989). 'Aspectos Hidrológicos del Control de Crecidas,' *Journal of Chilean Society of Hydraulic Engineering* 4, N°2.
[23] Andrade B. and H. Peña, 'Chilean Geomorphology and Hydrology: Response to Global Change, In *Earth System Responses to Global Change: Contrasts between North and South America*. Harold Mooney, Eduardo Fuentes, Barbara Kronberg (eds.), London: Academic Press, 1993.

At national level, particularly in many poorer countries, hydrological information systems have been allowed to decay under pressure to allocate scarce resources to more immediate needs. When faced by budgetary restrictions, hydrology is often one of the first functions to be sacrificed. Unfortunately, once records are lost or 'broken', it is very difficult to reinstate them. This is not just a problem of developing countries. Even in the rich world, monitoring targets have not been met as recent reports from the United States have demonstrated.[24]

There are a number of reasons for this decline in data availability. Aside from internal conflict and budgetary constraints, there are cases where data is available but, as competition over water resources grows, there is a reluctance to share it with other stakeholders.

There is also an understandable belief that the remote sensing technologies that have transformed knowledge about the atmospheric system have done the same for the hydrological system – which is unfortunately not true. Although work is underway to find ways to use remote sensing to provide information on stream flows and water quality, it is not yet at the point where models can be widely and effectively applied. Even when new methods are developed, physical observations will continue to be important to 'ground truth' remote sensing.

The IPCC technical summary once again highlights these issues:

> **Several gaps in knowledge exist in terms of observations and research needs related to climate change and water.** Observational data and data access are prerequisites for adaptive management, yet many observational networks are shrinking. There is a need to improve understanding and modelling of changes in climate related to the hydrological cycle at scales relevant to decision making. Information about the water-related impacts of climate change is incomplete, especially with respect to water quality, aquatic ecosystems, and groundwater, including their socio-economic dimensions. Finally, current tools to facilitate integrated appraisals of adaptation and mitigation options across multiple water-dependent sectors are inadequate.[25]

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24 Support for USGS Streamgaging Programs, letter of petition to Chairman of US Congress committee, House Appropriations Subcommittee on Interior, Environment and Related Agencies, Feb 2008: at http://www.asiwpca.org/home/docs/StreamgageLtr2House.pdf

25 *Climate Change and Water*, p. 4.

2.2. The social and economic dynamics

Changes in the availability, timing and reliability of rainfall and the water resources that flow from it will impact on all water using sectors. These impacts, in turn will affect the broader dynamics of national economies as well as environmental and social needs, particularly in poorer societies. Specifically, since effective water management is important for the achievement of many of the Millennium Development Goals, these impacts could also threaten the sustainability of progress on the Goals. But climate change's impact on water resources has implications far beyond the MDGs.

The changes in distribution and timing of rainfall will change patterns of access to water, creating new surpluses in some areas and increased competition in others. Managing these evolving hydrologies will impose significant demands on water management.

The increased variability of rainfall will impact growth potential and the costs of achieving water security. The evidence is that variability can be a greater management challenge than scarcity in that both sides of the equation (too little water and too much water) need to be managed, and managed under greater uncertainty. Studies have shown that, while there is little correlation between water scarcity and economic development, a clear correlation exists with variability (see Box 1).[26]

As climate variability increases, so too does the cost of the infrastructure, information and systems needed to cope with it. Looked at another way, because increasing variability increases the cost to society of failures to manage it effectively, greater investments should be made to avoid such failures. The major impact of climate change in many areas may be to increase the cost of water services and in particular the cost of achieving reliability in service delivery. This will not only be the case for drinking water, but also for agriculture and power production as well as for industry.

Ecosystem water use will be put under extreme pressure as the costs of water rise. Few countries have effective mechanisms to assure adequate water for ecosystems, so ecosystem water use is routinely the first use foregone.

The increased incidence of catastrophic events such as flood and drought will impact lives, livelihoods, land values and investment incentives in vulnerable

[26] Casey Brown and Upmanu Lall, 'Water and Economic Development: The Role of Variability and a Framework for Resilience,' *Natural Resources Forum* 30, No. 4 (2006): 306-317.

areas. While readiness and insurance schemes as well as water management interventions will be instrumental in addressing these risks, the prospects for increasingly vulnerable areas will change. In general, more vulnerable areas are inhabited by poorer populations who are less able to move away from hazards or uncertainties than more affluent populations. As vulnerable areas become more vulnerable – to floods, sea level rise, groundwater intrusion, loss of arable land – the poor are likely to be disproportionately hurt.

Changing water security conditions will drive changes in the spatial location of economic activities. On balance, economic activity will be driven toward water secure areas and away from insecure areas. Over time, changing water security conditions may also affect the structure of an economy – its sectoral mix and the rules by which it operates – as water affects sectoral economic returns.

Globally, trade in water-intensive products ('virtual water') may increase as patterns of water security shift. In the absence of confounding incentives, trade should promote greater water-intensive export production in water rich areas, and greater imports of water-intensive products in water scarce areas.

This section considers in more detail how, through its impact on water resources, climate change will impact on different dimensions of social and economic life.

Changing dynamics in urban areas

In many situations the major impact of climate change will be to increase the cost of providing even the most basic services, thereby reducing the availability of services in poor countries and communities. Urban areas will be under enormous population pressures in the coming years, resulting in strain on existing services and pressure to expand services – particularly to the poor. In Africa and Asia the urban population is expected to double between 2000 and 2030. In 2030 over 80% of urban dwellers will live in the cities of the developing world.[27] Changes in rainfall patterns and stream flow will have a direct impact on human settlements, so many of which are already unable to provide reliable, affordable services.

The impacts of climate change will not be limited to the capacity to supply potable water but will also apply to the capacity to dispose of wastes from large urban communities and the costs of building and maintaining other types of infrastructure. Some of the ramifications are obvious:

[27] UNFPA, *State of World Population 2007: Unleashing the Potential of Urban Growth.* New York: United Nations Population Fund, 2007.

- Water supply is a costly service to provide to large settlements and, if availability of water is reduced by climate change, larger conurbations will have to change their consumption patterns or bring their water from further afield.

- Any increase in the intensity of rainfall, and therefore flooding, as a consequence of climate change will increase the cost of roads and stormwater drainage as well as of flood protection works.

There will also be less direct effects:

- If stream flows are reduced and thus also dilution capacity, treatment must be intensified to maintain the water quality of receiving waters or make water available for reuse. Municipal wastewater collection and treatment[28] is already the most costly element of infrastructure required to meet MDGs for health, water and environmental protection,[29] and, since treatment costs increase exponentially with the degree of treatment required, climate change could add substantially to the burden of meeting these MDGs.

- Flood risk affects the area of land available for settlement as well as the cost of protecting vulnerable land from flooding (a related but separate challenge to that of coping with the challenge of sea-level rise, which is relevant for many coastal cities, but is not considered here).

- Bringing water from further afield not only increases the cost of water but also expands the area affected by competition with cities for water. This will have economic impacts, whether through higher prices for rural products or the aggravation of rural unemployment, potentially leading to urban migration.

Changing role of large industry, a major water user and polluter

Water-intensive industries will also feel the impact of climate change. Water security is increasingly being seen as a 'supply chain' issue in the private sector.[30] Rising water demand and uncertainty regarding both the quantity and quality of water available to industrial users can threaten production. For

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28 A. Bahri, 'Managing the other side of the water cycle: Making wastewater an asset,' GWP-TEC Background Paper 13. Stockholm: Global Water Partnership, 2009.

29 J. Winpenny, 'Financing water for all,' Report of the World Panel on Financing Water Infrastructure, presented at the Third World Water Forum, 16–23 March, 2003, Kyoto.

30 The World Economic Forum, 'Managing Our Future Water Needs for Agriculture, Industry, Human Health and the Environment,' Discussion Document for the World Economic Forum Annual Meeting 2008 (Geneva: The World Economic Forum, 2008).

industrial agriculture and agro-processing, this will be further compounded by shifting agricultural water patterns and crop water requirements. In response, many industries are now focusing on securing their water rights and minimizing their water footprints, and food and beverage industry alliances such as the Sustainable Agriculture Initiative have begun to invest in water management training for their supply chain farmers.

Traditionally, many large industries – from textiles and leather processing to pulp, paper and steel production – not only used large volumes of water in their production processes but also disposed of large volumes of effluent, which polluted the streams into which they were discharged and, in extreme cases, rendered receiving waters unusable for other purposes. Growing concerns about environmental impacts, linked also to climate change, have seen the start of a more responsible approach, often driven by tough national regulations, particularly in the richer countries of Europe and North America.

One response to this has been for industries to seek to adapt their production methods to reduce their water use and discharges – in some cases, even adopting closed-cycle, zero-discharge processes. While it is often feasible to achieve close to zero-discharge production, this usually requires substantial innovation and investment. The competitive implications of different national standards have already led to active efforts to establish broad benchmarks against which industries can be assessed – and pressured – to improve their performance.

Changing dynamics in agriculture

Agriculture is the sector of the economy that, in most countries, accounts for the largest proportion of water abstracted from rivers and underground sources. This is in addition to 'dryland farming' that uses rainfall directly. In the poorest countries, it also usually accounts for the greatest share of employment. Climate change will impact agriculture in many different ways. These have been well summarized in the most recent World Water Development Report (see Table 1).

While the challenges faced by 'dryland' farmers and those who practice irrigation have the same origins, they are often very different. Dryland farmers are affected by both the short and longer-term variability in rainfall. Irrigation farmers have some mechanisms to protect them from short-term variation, but they may be even more vulnerable when truly extreme events occur and their supplies fail. And all farmers are vulnerable to damage caused by extreme wind, storms, and flooding.

Table 1. Typology of climate change impacts on major agricultural systems

System	Current status	Climate change Drivers	Vulnerability	Adaptability
Snow melt systems				
Indus	Highly developed, water scarcity emerging. Sediment and salinity constraints.	20-year increasing flows followed by substantial reductions in surface water and groundwater recharge. Changed seasonality of runoff and peak flows. More rainfall in place of snow. Increased peak flows and flooding. Increased salinity. Declining productivity in places.	Very high (run of river), medium high (dams).	Limited possibility for adaptation (all infrastructure already built).
Ganges-Brahmaputra	High potential for groundwater, established water quality problems. Low productivity.		High (failing groundwater tables)	Medium (still possibilities for ground-water development).
Northern China	Extreme water scarcity, high productivity.		High (global implications, high food demand with great influence on prices).	Medium (adaptability is increasing due to increasing wealth).
Red and Mekong Rivers	High productivity, high flood risk, poor water quality.		Medium.	Medium.
Colorado River	Water scarcity, salinity.		Low.	Medium, excessive pressure on resources.
Deltas				
Ganges-Brahmaputra	Densely populated. Shallow groundwater, extensively used. Flood adaptation possible; low productivity.	Rising sea level. Storm surges, and infrastructure dam-age. Higher frequen-cy of cyclones (East and South-East Asia. Saline intrusion in groundwater and rivers. Increased flood frequency. Potential incerase in groundwater recharge.	Very high (flood, cyclones).	Poor, except salinity.
Nile River	Highly dependent on runof and Aswan Storage – possibly sensitive to upstram development.		High (population pressure).	Medium.
Yellow River	Severe weather scarcity.		High.	Low.
Red River	Currently adapted but expensive pumped irrigation and drainage.		Medium.	High, except salinity.
Mekong River	Adapted groundwater use in delta; sensitive to upstream development.		High.	Medium.

System	Current status	Climate change Drivers	Vulnerability	Adaptability
Semi-arid and arid tropics: limited snow melt and limited groundwater				
Monsoonal: Indian subcontinent	Low productivity. Overdeveloped basin (surface water and groundwater).	Increased rainfall. Increased rainfall variability. Increased drought and flooding. Higher temperature.	High.	Low (surface irrigation); medium (groundwater irrigation).
Non-monsoonal: sub-Saharan Africa	Poor soils. Flashy water systems. Over-allocation of water and population pressure in places.	Increased rainfall variability. Increased frequency of droughts and flooding. Lower rainfall, higher temperature. Decreasing runoff.	Very high. Declining yields in rainfed systems.	Low.
Non-monsoonal: Southern and Western Australia	Flashy water systems. Over-allocation of water. Competition from other sectors.		High.	Low.
Humid tropics				
Rice: Southeastern Asia	Surface irrigation. High productivity but stagnating	Increased rainfall. Marginally increased temperatures. Increased rainfall variability and occurrence of droughts and floods.	High.	Medium.
Rice: Southern China	Conjunctive use of surface water an ground water. Low output compared with Northern China.		High.	Medium.
Mediterranean				
Southern Europe	Increasing pressure on water.	Significantly lower rainfall and higher temperatures. Increased water stress. Decreased runoff. Loss of groundwater reserves.	Medium.	Low.
Northern Africa	High water scarcity.		High.	Low.
West Asia	Heavy pressure on water.		Low.	Low.
Small Islands				
Small islands	Fragile ecosystems. Groundwater depletion.	Seawater rise. Saltwater intrusion. Increased frequency of cyclones and hurricanes.	High.	Variable.

Source: World Water Assessment Programme, The United Nations World Water Development Report 3: Water in a Changing World, (Paris: UNESCO, and London: Earthscan, 2009), p. 114.

In this context, agriculture is all about risk management. Every season, dryland farmers have to make a decision in the face of uncertainty. Plant too soon and seedlings may fail to develop if soil moisture is inadequate or there is a dry spell early in the season. Plant too late and there may not be enough time for crops to reach maturity, or they may become more vulnerable to pests and disease.

In these circumstances, climate change could have disastrous impacts. Regional studies suggest that, in sub-Saharan Africa, a worst case scenario could see crop net revenues fall by as much as 90% by 2100, with small-scale farms being the most affected. This would have dramatic livelihood implications[31] although there is the possibility that adaptation could reduce these negative effects.

Large-scale farmers address these uncertainties on a seasonal basis by using insurance and other financial instruments as well as technologies to protect themselves. Small scale and poorer farmers often do not have these options open to them. However, short and medium-term weather forecasting may make it possible to give farmers useful information about seasonal trends, enabling them to plant at the appropriate times.

In some areas, longer-term weather trends can be predicted with some degree of accuracy, helping dryland farmers to make seasonal decisions. However, the value of longer-term predictions tends to be limited to certain areas, certain seasons and even then they are often of limited reliability. Longer-term predictions are often so general as to be virtually useless for the planning of rainfed production (the southern African forecasts, for instance, simply give an estimation of the probability of normal, above average or below average rainfall; very rarely is such a prediction made with more than a 50% probability).[32]

Other responses to climate change include choosing crops and seed varieties more appropriate to the new conditions. Again, in this area, large commercial farmers are better able to take adaptive actions. The ability of poorer farmers and poorer countries to cope is more limited. Traditional seed varieties, even

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31 See for example, Peter G. Jones and Philip K. Thornton, 'Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change,' Environmental Science & Policy, Volume 12, Issue 4, June 2009, Pages 427-437.
32 See, for instance, Statement from the 12th Southern Africa Regional Climate Outlook Forum (SARCOF-12) held in Pretoria, South Africa from 27 – 28 August 2008, http://www.sadc.int/dmc/SARCOF/Sarcof12_Statement28_08_09.pdf.

where they have been retained, may no longer be suitable in their original areas. And the agricultural research and extension services, which should lead the process of identifying options and supporting farmers to adopt them, have often been drastically reduced.

Changing economics of irrigation, the growing value of certainty

Given the threat of greater variability in rainfall and streamflow, the logical response is to invest in the capacity to manage water, essentially, paying for greater security and reliability. This does not necessarily mean storage in large dams – there are many indigenous farming systems that are based on the construction of small local reservoirs to provide secure water supplies during dry seasons. Indeed, one advantage of local storage – always assuming that the local rainfall is adequate – is that it does not require major works to transfer water from stream to field.

There are complexities to this option however, particularly in arid, water-stressed regions, where most of the available water is already being used. Large numbers of small shallow dams lose much more water to evaporation than large deep ones, a situation that will be exacerbated under conditions of increased aridity. Storing water underground is another local option. But creating structures to increase recharge will also reduce runoff from rainfall, which may adversely impact downstream water users.

While irrigation, whether supplied from 'run of river' flows or from water stored naturally underground or artificially in man-made reservoirs, appears to be more reliable than rainfall, its reliability may be misleading. Where water is taken directly from rivers, irrigation is vulnerable to serious drought. When irrigation is taken from storage reservoirs, it is often possible to give a season's warning of possible shortages, but where management control is weak farmers can't count on such early warning systems.

A similar situation applies with groundwater. Communities rich in underground water are fortunate in that they neither have to store water nor transport it great distances. For this reason, many such communities have developed thriving agricultures based on the abstraction of local groundwater, helped by better pumping technology and the easy (and often) subsidised availability of pumping energy.

An additional advantage is that the groundwater cycle is slower than that of surface water and, as a result, groundwater reserves are not affected as immediately as surface water stocks by periods of drought. However, this can also be a disadvantage in that underground resources are harder to visualize and control.

The result is that, in many regions where there is large-scale reliance on groundwater, the resources are often over-exploited, and often without users being aware of the risks they are running. North China, large areas of India, most of the mid-East and substantial parts of the Western USA are systematically 'mining' their reserves. Many areas risk disaster unless they bring their current use in line with the rate of aquifer recharge. Climate change simply brings more uncertainty into groundwater management.

Many farmers and communities are increasingly reliant on managed water, from storage or underground sources rather than direct rainfall, for their livelihoods. In general, where crop prices offer sufficient return and the cost or scarcity of water provides sufficient incentive, people have proved willing to invest in enhanced water efficiency. The investments in water management made by farmers, singly and as collectives, have enabled them to sustain increases in production and withstand the vagaries and variabilities of the climate. Where farmers have made their own investments, they are often very conscious of the cost of their water and are more likely to practice more efficient water use.

Irrigated agriculture is crucial to global food production and the FAO predicts its importance will increase. Developing countries are expected to expand irrigated areas by some 20% before 2030.[33] Today, 40% of crop production comes from the 16% of agricultural land that is irrigated[34] and, globally, the area under irrigation has been growing steadily, at about 5% per decade.

This pattern of investment leading to greater productivity and increased ability to manage climate variability and risk is potentially an important driver of poverty reduction, as well as contributing substantially to the world's ability to feed a growing population. However, to the extent that climate variability increases, so too will the cost of infrastructural methods to cope with it. Unless mechanisms are developed to compensate for this, the consequence could be increasing poverty and a reduced ability to meet the world's food needs.[35]

In economic terms, the picture is by no means all bleak given the fact that agricultural production in some areas of the world is likely to benefit from climate change, and the indications are that food supply could continue to be

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33 FAO, 'World Agriculture: Towards 2015/2030', Rome: FAO, 2002.

34 David Tilman, Kenneth G. Cassman, Pamela A. Matson, Rosamond Naylor and Stephen Polasky, 'Agricultural sustainability and intensive production practices, *Nature* 418, (8 August 2002): 671-677.

35 E.g., C. Brown and M. Carriquiry (2007), 'Managing hydroclimatological risk to water supply with option contracts and reservoir index insurance, *Water Resour. Res.*, 43, W11423.

met with changing patterns of production.[36] However, the social impacts of such shifts could be devastating since they would occur at the expense of the livelihoods and food security of some of the poorest countries and communities and perhaps longer-term sustainability as well.

Changing dynamics in hydropower, the demand for renewable energy

Electricity generated by hydropower is still by far the largest source of renewable, non-CO_2 producing energy globally (see Table 2). By exploiting the potential energy of the water as it runs downhill and to the sea, a reliable and flexible supply of electricity can be generated to help replace the use of fossil fuels or nuclear power. Hydropower generation also overcomes one of the greatest barriers to the use of renewables because it can be 'stored' in the form of high-level dammed water, to be released through turbines when power is required. Indeed 'pumped storage', already an integral part of many conventional power grids, is one of the most flexible and cost-effective ways of storing power from newer, more variable, sources of renewable energy such as solar or wind.

The development of hydropower appears to have great potential, offering an obvious strategy both to promote climate change adaptation (where drought and flood control benefits can be derived from multipurpose dams) as well as climate change mitigation through the development of renewable energy sources. According to the International Energy Agency, electricity generation from hydropower and other renewable energy sources is projected to increase at an average annual rate of 1.7% from 2004 to 2030, for an overall increase of 60% through 2030.

But hydropower development also has many challenges. To tap the flow of water, it must be captured, controlled and often stored, which requires major engineering works. Although, once built, operating costs are relatively low, the initial financial cost of construction is high. And in many cases, the social costs can be even higher. In China's Three Gorges scheme, which by itself generates more energy than most countries consume, the cost of relocating over a million people affected by the dam as well as environmental mitigation measures exceeded the cost of constructing the dam and power station.[37]

[36] Comprehensive Assessment of Water Management in Agriculture, *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*, (London: Earthscan, and Colombo: International Water Management Institute, 2007).

[37] Yang Xiaoliu and Mike Muller, 'Taming the Yangtze River by enforcing infrastructure development under IWRM' in *Integrated Water Resources Management in Practice Better Water Management for Development*, Roberto Lenton and Mike Muller (eds.), London: Earthscan, 2009.

Table 2. Grid-based renewable power capacity in 2003

Generation type (gigawatts)	Capacity in all countries	Capacity in developing countries
Small hydropower	56.0	33.0
Wind power	40.0	3.0
Biomass power*	35.0	18.0
Geothermal power	9.0	4.0
Solar photovoltaics (grid connected)	1.1	<0.1
Solar thermal power	0.4	0
Total ‘New Renewable‘ Power Capacity	**141.5**	**58.0**
For comparison:		
Large hydropower	674.0	303.0
Total electric power capacity	**3,700.0**	**1,300.0**

*Excluding municipal solid waste combustion and power from landfill gas.

Source: Water a Shared Responsibility: World Water Development Report 2, (Paris: UNESCO and New York: Berghahn Books, 2006), p. 315.

Uncertainty about future river flows is an increasingly important challenge for the design, promotion and operation of hydropower installations. Climate change means that the assumptions about how much water will be available to store and run through existing turbines will have to be revised – both up and down. Already many countries dependant on hydropower have experienced shortfalls in their electricity supply due to unprecedented decreases in water availability (see Box 4).

A further concern is that dams are designed to withstand the ‘probable maximum flood,’ which is based on estimates using past hydrology. Again, these estimates will need to be revised in the light of climate change to determine if the margin of safety is still adequate and if operating rules need to be revised. Changing flow regimes will also alter the economic viability of hydropower schemes and may lead to a reduction or an increase in their generating potential. For new schemes, it adds uncertainty to decision-making.

Box 4: Water shortages lead to power shortages in hydro dependant countries

Uganda's electricity supply, already constrained by delays in the building of a dam just downstream of the existing Owen Falls plant, was further cut when the level of Lake Victoria fell an unprecedented two metres in the early 2000s. In Malawi, Lake Malawi, the country's main source of power, suffered similar problems while in Kenya, huge electricity tariffs tripled when hydropower supplies were reduced and the country had to resort to oil-fired power stations. In all three cases, while extended periods of low rainfall were the main cause, land use changes, particularly the expansion of cultivation by small farmers, were also important contributors.

Furthermore, despite wide consensus on the need for clean energy, hydropower remains controversial. This is largely because of environmental objections to the impact of dams on river ecosystems (through fragmentation and changed flow patterns) as well as, in some cases, to the impact on communities displaced by their construction. It has also been suggested that rotting vegetation in flooded dam basins can generate methane, a greenhouse gas, although recent lifecycle assessments suggest that hydropower projects emit low overall net greenhouse gases.[38]

The controversies surrounding large dams led to a decision by the international community not to recognize 'large' hydropower as a source of renewable energy – although 'small' hydropower is considered to be renewable. This excludes large hydropower from certain sources of subsidy and funding (see Box 6). Ironically, one reason advanced for excluding large hydropower from specific climate mitigation funding is that it would 'crowd out' other, newer, but less economically efficient renewable energy technologies.

Hydropower has been extensively tapped in the developed countries of Europe and North America, and today accounts for approximately 20% of world electricity production. Substantial undeveloped potential remains in Asia, Africa and Latin America. Since rich and middle-income countries have well developed hydropower systems (see Figure 5), it is the opportunities in the poorer, predominantly South Asian and African countries that are being constrained.

[38] The IPCC does not consider methane generated in reservoirs to be a significant source of greenhouse gases, noting that 'while some GHG emissions from new hydroelectric schemes are expected in the future, especially in tropical settings… in the absence of more comprehensive field data, such schemes are regarded as a lower source of CH4 emissions compared to those of other energy sector or agricultural activities' Hydroelectric power is therefore not treated as a separate emission category in SRES. See IPCC Special Report on Emissions Scenarios, UNEP/WMO 2006.

Box 5: The large dam controversy: Mphanda Nkuwa in Mozambique

One example of a project that has been delayed, in part by the controversy about large dams and whether 'large hydro' can be considered to be renewable, is that of Mphanda Nkuwa. This is a large hydropower project by international standards with a planned capacity of 1,300 MW, making it slightly smaller than Cahora Bassa, which was commissioned in the mid-1970s and has an installed capacity of 2,075 MW.

Mphanda Nkuwa, located on the Zambezi River between Cahora Bassa and Tete, is rated as one of the most attractive undeveloped hydropower projects in the world. The hydrological risk has been limited and well documented with long time-series of water flows. The geological risk is low and the dam site can be developed at a cost of US $640 per kilowatt of installed capacity, which compares very favourably with coal fired power, particularly since operating costs are much lower. Since existing upstream dams, such as Cahora Bassa, Kariba and Kafue Gorge, regulate the Zambezi River, the project can be developed as a run-of-river hydropower plant requiring a small reservoir relative to its size and with very limited negative environmental impact, affecting very few people.

Yet its construction has been delayed for years, even at a time when regional electricity shortages were resulting in massive investment in climate-unfriendly coal fired power stations.

The dynamics of risk and reliability in multi-sector systems

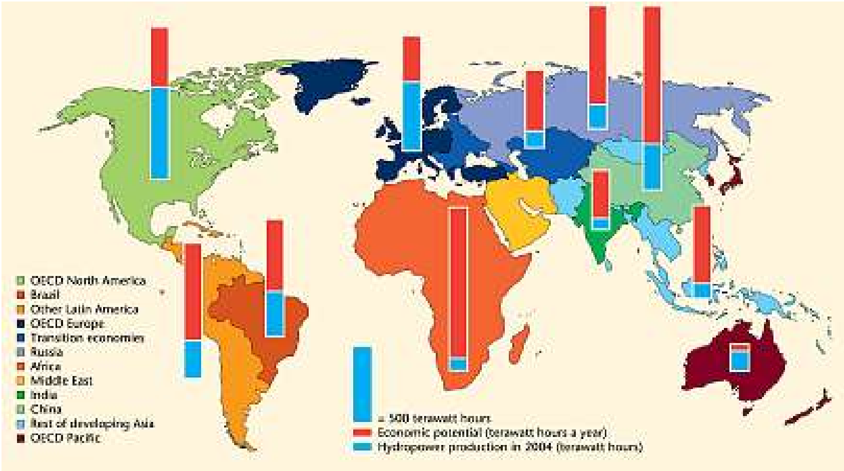
The challenges faced by new hydropower projects highlight the importance of locating them within a broader water management framework, since their impacts often go far beyond power production. These impacts are not only negative. Multi-purpose developments have the potential to yield a range of benefits, including flow regulation and flood management and a more reliable supply of water for agriculture, industry and urban consumption.

As an example, in addition to its huge power generating role, China's Three Gorges project has helped to protect millions of people from floods, has improved navigation in support of regional development of the hinterland and has provided an additional source of water for the arid north eastern part of the country.[39] Its success derives in part from the fact that it was, from the beginning, conceived as part of a program of regional development rather than as a power project.

This multisectoral approach is increasingly becoming the norm as the imminence of climate change forces reconsideration of old assumptions in all sectors. In many cases, what is emerging is a better understanding of the nature of hydrological risk and its linkages to broader societal risks as well as of the value of predictability and reliability and the need for deliberate measures to

[39] Xiaoliu and Muller, 2009.

Figure 5. World potential and current hydropower production, 2004



Source: UN World Water and Development Report 3, p 119.

manage it. Indeed, one indicator of effective water resource management is the extent to which it helps different sectors manage their risks.

A product of better understanding is the willingness of users to pay for water management that mitigates risks, reflecting the value they place on the reliability of services and the negative consequences and costs they suffer from uncertain supply. For agricultural enterprises, the reliability of the water supply is more important for perennial crops than for annuals. Perennials often take many years of investment to bring into full production and their loss thus has more serious consequences than for annuals. Farmers growing perennial crops could thus be expected to pay more for allocations with greater reliability.

In industry, water often has a much greater production value than it does in agriculture. Thus industries ought to be prepared to pay more for higher levels of supply security – and in many jurisdictions, they do.

In terms of determining what allocations should be privileged in situations of scarcity, it is not just a matter of who can pay the most; there are also social considerations. For example basic domestic water use, while it may not be conventionally valued, is usually afforded a priority above all others, reflecting the inherent value of human life. Water used in industry often generates more 'jobs per drop' than water used in agriculture, but, in many countries, this does not help the poorest people, whose livelihoods depend on agriculture and who have no economic safety net. Effective water management systems will reflect a balance between economic and social priorities either through pricing or through allocation systems or through a mix of both.

Box 6: Hydropower and climate change funding

Although hydropower is essentially a renewable energy source, at present, hydropower investments can only benefit from climate mitigation funding under a very constrained set of conditions. Specifically,

- Hydropower projects which are 'too large' are effectively excluded from Clean Development Mechanism funding unless they meet specified 'power density' criteria, in terms of the lake area per unit power generated;
- The European Union Emissions Trading System (ETS) framework (the largest multi-national, emissions trading scheme in the world) places another hurdle for CDM hydropower projects over 20 MW, requiring compliance with relevant international criteria and guidelines including those in the World Commission on Dams (WCD) 2000 Report;
- Similar constraints apply in the USA where the current US Climate Change Bill defines only 'incremental' hydropower as renewable.

The contribution of CDM funds to a hydropower project typically has the effect of increasing its rate of return by 2 or 3 percent according to the IHA – enough to turn a borderline project into a financially bankable one. Thus the direct restrictions and the transaction costs imposed by the broader conditionality place limits on the potential benefits of hydropower:

- They block potentially beneficial mitigation activities that would reduce greenhouse gas emissions;
- They increase the cost of energy in communities that do not have other options to thermal power; and
- They limit the possibility of funding multi-purpose water resource projects with adaptation benefits in poor communities.

The situation is changing on a number of fronts:

- While the WCD report has not proved to be a particularly practical compliance/administration tool, one outcome of the WCD process has been to force the hydropower sector to address its sustainability performance more openly and directly.
- The emergence of leading developing countries, for example China and countries in the Middle East, is changing the bilateral financing/aid landscape for the development of infrastructure, including hydropower.
- Perhaps as a result of this, there is now renewed willingness on the part of European and North American countries to review their approach.

The IHA's Hydropower Sustainability Guidelines (2004) (HSG) and a Hydropower Sustainability Assessment Protocol (2006) (HSAP) are now being reviewed by a Hydropower Assessment Forum whose members include representatives of developed and developing country governments; the hydropower sector; social and environmental NGOs, including WWF and The

Box 6: Hydropower and climate change funding, cont.

Nature Conservancy; as well as commercial and development banks. The project aims to establish a broadly endorsed sustainability assessment tool to measure and guide performance in the hydropower sector.

In addition, a research project is underway, led jointly by UNESCO's International Hydrological Programme and the IHA, to review greenhouse gas emission from reservoirs, which has been put forward as a reason for constraining large hydropower development.

> The issue of the GHG status of freshwater reservoirs plays an important role in these discussions; however, there is currently a significant problem because there is **no scientific consensus on how to measure the GHG status of freshwater reservoirs**. This is causing difficulties from global to local action. For example, the IPCC is waiting on further scientific progress for guidance on **national GHG inventories**, and the UNFCCC is looking for methodologies (measurement and predictive modelling) to quantify carbon offset for **emission trading**. More generally, policy making on energy, water and climate action is compromised by the current lack of understanding. This has a global impact, and especially on developing countries.[40]

Since the CDM and ETS will be reviewed after the Copenhagen Conference in December 2009, there will be an opportunity to put in place a regulatory regime that considers the adaptation benefits from large, multi-purpose dams as well as ensuring their optimal use for the generation of renewable energy to mitigate carbon emissions.

The recent major drought in Australia's Murray-Darling Basin provided an example of this as water restrictions were imposed, administratively, to maintain supplies to those sectors most at risk. As the former head of Australia's Murray-Darling Commission explained,

> The use of water there is managed through a system of water rights, defined in terms of volumes and security of supply. During the current extensive drought, many water users are receiving only a small fraction of their 'normal' entitlement. This is enforced entirely through the water-rights system—not through pricing mechanisms—enabling water to be reallocated from low-value to high-value uses; despite massive reductions in rainfall and river flows, there has been little impact on the value of agricultural production in the Basin.[41]

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[40] UNESCO/IHA Project (2008/2011), 'GHG Status of Freshwater Reservoirs,' Project Summary, (London: IHA, 2008).
[41] Don Blackmore and John Briscoe, Letter to the Editor, The *Economist*, 2 October 2008.

Water storage is often seen as the obvious strategy to improve water supply reliability, yet there are many alternatives. In some cases, systems of water rationing create a relatively sophisticated system of 'staged reliability' of supply, whether through urban hosepipe bans or cutbacks in agricultural allocations. The application of such rationing is often evidence of an effective and appropriate management strategy, although this is not necessarily obvious to the broader user community. And there are other approaches that can be used. Food stocks can be built against occasional drought reduced harvests, financial 'storage' in the form of insurance can also protect against supply failures and help to smooth over the impact of climate variability.

In many cases, physical water storage provides the greatest benefits at the least cost, but it may not in itself improve reliability. Storage is only one element of the physical infrastructure required.

Many countries, particularly poorer countries in arid regions of Africa, do not have adequate storage. Even where there is significant storage, as in Southern Africa where two of Africa's largest dams have been built on the Zambezi, there is not necessarily water security for all water users unless extensive transport and delivery infrastructure is built as well. A similar situation is found where there is natural storage. For example Eastern Africa's lakes store large volumes of water but communities remote from the lakes cannot access this water.

And storage can sometimes be a mirage. The existence of large stocks of water can create the impression of plentiful availability. But it is the ability of the storage to support (and regulate) the outflows that matter, which is why very large water bodies, such as North America's Great Lakes, can support only surprisingly small abstractions on a sustainable basis.

One of the challenges (and opportunities) of managing multisector systems is identifying approaches that fulfil multiple objectives. Thus water can be stored to provide guarantees of supply to downstream users, to generate electricity, and to reduce the intensity of flood events. To achieve all these benefits however, appropriate operational priorities have to be set.

A classic case highlighting the dangers of failing to plan and operate systems for multiple objectives occurred in the operation of the Cahora Bassa hydropower project on the Zambezi River, shortly after Mozambique gained independence from the colonial power, Portugal in 1974. The Cahora Bassa

Dam, still very new, was operated by a Portuguese company whose objective at the time was to maximize revenue to amortise the huge construction costs. As a result, it maintained dam levels as high as possible to get as much water through its turbines at as high a pressure as possible. This meant that when heavy rain occurred upstream, the dam could not store any of the incoming waters and they were discharged down river in a flood that devastated downstream communities.

Clear criteria are needed to choose between multiple objectives in the design and operation of large dams. So, the operating rules for China's Three Gorges Dam address both flood control and hydropower. They require that dam levels be reduced substantially as the flood season approaches to create 'space' to store floodwaters, absorbing the impact of floods that would otherwise threaten many millions of people in downstream communities. While lowering the reservoir level substantially reduces the electricity generation potential, this is considered necessary to obtain optimal benefits from the dam for the Yangtze basin community. Other functions, such as transport and water supply are also considered in the operating rules.

To the extent that advance information is available about seasonal rainfall patterns, the operating rules can be fine-tuned to maximize benefits to all users. Financial instruments can also be designed to the mitigate impacts of variability on multiple user groups.[42] This can only be done, however, if there is storage available in the system. In this context, the importance of hydropower development is that it can fund the storage that supports adaptation while also contributing towards mitigation by producing clean, renewable energy.

Changing dynamics for the environment

If the water using sectors of society face substantial challenges as a consequence of climate change, so too does the natural environment of which water resources form a part. Indeed, climate change throws into question some of the basic assumptions behind current approaches to environmental management and protection that seek to sustain existing ecosystems by minimizing human interference, since without human interference, ecosystems will inevitably be affected by climate change. The final state of the environment thus becomes, ever more explicitly, as much a matter for human design as a product of natural processes.

[42] E.g. Philippines Brown, C., and M. Carriquiry (2007), Managing hydroclimatological risk to water supply with option contracts and reservoir index insurance, *Water Resources Research*, 43, W11423, doi:10.1029/2007WR006093

A wide range of environmental changes will be driven by climate change and by human responses to it. Changing temperatures and hydrology will impact on vegetation cover as well as on river and wetland ecosystems and biodiversity more generally. Mitigation efforts such as forest management and land use practices as well as potential increases in hydropower development and biofuel production will also affect ecosystems.

Where water becomes scarcer, the existing natural environment will likely be the first to suffer. Few countries have effective mechanisms in place to ensure that adequate water remains in rivers and aquifers to sustain aquatic ecosystems and their biodiversity. In most cases, ecosystems are the first to lose the competition for water as other users (households, agriculture and industry) continue to withdraw water for production. In a changing climate, establishing an appropriate balance will be even more difficult than it is today.

Hydrological variability, climate change and economic growth

Since the variability of rainfall and river flows will increase with climate change, the implication is that this will significantly impact economic growth – particularly in poor countries. Indeed, research into the economic impact of scarcity and variability suggests that the only countries and regions that have escaped the drag imposed by climate variability on development have been those with the financial and intellectual resources to manage it.

Both action, and—importantly—inaction, to cope with hydrological variability will entail significant economic, social and environmental costs. The costs of dealing with increased hydrological variability will be substantial. And these costs will be incurred whether action is taken or not. Thus, in areas vulnerable to increased flooding, the social, political and financial costs of actions such as relocating vulnerable households, strengthening flood protection structures and early warning systems will have to be set against the costs of inaction which will be measured in terms of deaths and damage to property.

These costs and the circumstances that give rise to them must be understood and mindfully structured in the specific context in which they arise. There is no general prescription for dealing with the myriad of local circumstances. What will be important is to take a structured approach that considers the relevant issues, the possible responses, and provides a systematic approach to taking decisions.

Spatial patterns of development

Economic activity is likely to flow to areas of greatest water security, away from areas of uncertain supply or increasing water-related hazards. This in turn will increase competition in those water secure areas, potentially undermining the very water security that initially drew water users to the area.

In general, less secure areas are inhabited by poorer populations. As vulnerable areas become more vulnerable – to floods, sea level rise, groundwater intrusion, loss of arable land – the poor are likely to be disproportionately hurt.

Trade in water-intensive products ('virtual water') may increase as patterns of water security shift. While trade could mitigate some of the negative impacts of climate change, if water insecure countries are able to import food from water rich countries. However, recent food price volatility has heightened longstanding concerns over dependence on trade for significant amounts of food staples.

For wealthy nations, an emerging coping strategy in this regard appears to be the purchase of land overseas. For example Saudi Arabia recently purchased significant agricultural land in South/Central Asia, and China has invested in the Sudan and Mozambique while South Korea is reportedly proposing to farm in Madagascar. It has been suggested by the Chairman of Nestle, the world's largest food company, that this process is more about gaining access to water than to land.[43]

Changing water security conditions will also drive changes in the spatial location of human settlement. A recent report by CARE identifies droughts, floods, glacier melt, sea level rises and changing agricultural patterns as the key drivers of potentially massive, climate change induced, social disruption.

> The impacts of climate change are already causing migration and displacement. Although the exact number of people that will be on the move by mid-century is uncertain, the scope and scale could vastly exceed anything that has occurred before. People in the least developed countries and island states will be affected first and worst. The consequences for almost all aspects of development and human security could be devastating. There may also be substantial implications for political stability.[44]

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43 Peter Brabeck-Letmathe, 'The Next Big Thing: H20', *Foreign Policy*, May/June 2009.
44 CARE, 'In search of shelter: mapping the effects of climate change on human migration', CARE and CEISIN, 2009, p. iv.

Structural change in economies

If water security conditions change in a particular area, the returns to particular economic activities are likely to change. Water vulnerable activities are likely to decline as a share of economic production, while water resilient activities should grow.

Adaptation-oriented responses would promote technologies, infrastructure and water management practices that enhance resilience to hydrological variability, and encourage increased investment in more water resilient sectors of the economy.[45]

In this context, it is notable that improvements in water management in agriculture may depend significantly on the terms of trade for agricultural products. Unless farmers receive an adequate return for their crops, they will not be able to fund the investments in water efficiency that will enable them to cope with a reduction in available water. This will also limit their ability, in areas where water supplies are still constant, to reduce their water use and release water for other purposes.

While trade in 'virtual water' may help to sustain food production by ensuring that it is distributed to the areas of greatest potential, this process is likely to occur at the expense of the poor in areas of declining potential. Thus, while the world may have sufficient food, one impact of climate change may be that the poor in many countries could be left without the income needed to purchase it.

2.3 Compounding Factors

The impacts of climate change on different sectors of society pose weighty challenges for water resource management. Yet they are not the only threats on the horizon. Indeed, other drivers of change are at least as pressing in the short to medium term. These other drivers form an important part of the context within which water managers must respond to climate.

These drivers include: population growth, economic development and related changes in consumption patterns, technological developments, climate mitigation strategies and urbanization and land use change.

Population changes

Most measures of 'water stress' or 'water scarcity' are based on the amount of water available per person. While variability rather than absolute amount

[45] For example see 'Water in a Sustainable Economy' by Ger Bergkamp and Claudia W Sadoff in *State of the World 2008: Innovations for a Sustainable Economy*, (Washington, DC: Earthscan, 2008).

of water available is often more closely associated with development performance, the implications of water scarcity are still important. Particularly in Africa, but also in Asia and Latin America, growing water scarcity is primarily a result of growing populations competing for the same amount of water, rather than any change in the availability of the resource itself.

Economic development and related changes in consumption patterns
Where economic development results in rising personal incomes, peoples' consumption patterns change. Dietary changes in particular have implications for water demand. Specifically, a shift from grain to meat consumption is associated with substantial increases in the amount of water consumed per capita. Most changes in consumption as a result of rising standards of living will have the effect of expanding individuals' 'water footprints'.

Technological developments
There are many areas in which technological change affects water and its management. These can be beneficial, for example the development of water saving technologies that reduce pressure on the resource. However, there are many instances in which technological development has negative impacts on water resources. This is particularly the case with respect to water quality; many new chemical products and pharmaceuticals introduced into society are disposed of and disseminated through the water cycle with unpredictable consequences for human health.[46] The development of new energy sources such as oil shales poses significant threats to water quality in many areas.

Urbanization and land use change
Flooding is a major water resource management challenge even in the absence of climate change. The mounting costs of floods are due not only to changes in intensity and frequency, but to population growth, urbanization and land use changes that push populations and assets into vulnerable areas. So urbanization and land use planning can also be drivers that influence the way water impacts on society and society impacts on water.

Climate mitigation strategies
The idea that climate change mitigation strategies could themselves worsen the impact of climate change in the water sector is paradoxical but true. Pressures to expand hydroelectricity or to develop new sources of biofuels will

[46] See 'It's Time to Learn From Frogs' by Nicholas D. Kristof, *New York Times*, 28 June 2009, on concerns over endocrine disruptors in water supplies.

impact on water resources. Solving the energy challenge could thus aggravate pressures on water resources as well as putting pressure on food supplies. This is a good example of the need to consider impacts on water resources as part of the review of climate mitigation strategies.

Uncertainty and time horizons

Uncertainty pervades every aspect of climate change adaptation planning. This is seen by many as good reason to postpone action. Most impacts are expected decades in the future, and the scale of impacts could vary widely with a range of factors – the success and scope of mitigation efforts, the accuracy of today's models, the potential for non-linear tipping points that cannot be modelled, and so on.

But the timeframe for aligning water resources management responses is on a similar time-scale. Major water resources infrastructure, such as large reservoirs or pipelines, routinely takes over a decade to design and construct. Moreover they are extremely long-lived. The structures built today will still be standing – and hopefully operating – a hundred years from now. Similarly, hydrological data and information collected today will provide an invaluable basis for monitoring, understanding and managing the world's changing hydrology for decades to come.

While sequencing and prioritizing specific medium-term priorities is surely complex, it is timely and wise to focus now both on building our understanding of the challenges and our capacity to deal with them. It is equally important to seize existing opportunities for intervention, whether by enhancing river regulation and water storage options; by strengthening hydrological information systems, particularly for those strategic water resources we know little about, such as groundwater and glacier melt; and by introducing the difficult 'soft' measures such as conservation programmes and incentives to reduce pollution that will change our behaviour and make us less vulnerable in the future.

Box 7: Climate change in the Mediterranean region: Possible threats and responses

All climate change scenarios predict that the Mediterranean will be one of the most severely affected regions, with an increase in the intensity and frequency of floods and particularly of droughts and repercussions for the qualitative and quantitative state of water resources. These changes will exacerbate the already existing serious water stress in most parts of the region, including North Africa, the Middle East, and South-eastern and Southern Europe. However the impacts and their ramifications will not be uniform across the region as seen in the following overview:

North Africa

Climate change will intensify challenges of overcoming poverty and ensuring livelihoods. Increased competition is expected over water resources for agriculture, domestic use, tourism, etc, with annual water demand rising by $50km^3$. Health challenges (potential contamination of supply systems from sewage due to floods) will be exacerbated, which is likely to increase migration and the risks of conflicts between countries sharing water resources.

The consequences of climate change are likely to include: severe droughts, significant reductions (of the order of 50%) in run-off and stream flow and decrease of soil moisture due to reduced rainfall and higher temperatures, which in turn will lead to higher evaporation, aridity, increased risks of forest fires and desertification.

In the Maghreb, agriculture is dominated by non-irrigated, small-scale farms that are not modernising fast enough to feed growing populations. Increasingly frequent droughts are thus projected to decrease agricultural output by more than 20% (by 2080) with peaks of almost 40% in Morocco and Algeria. This may place strains on their economies, through increased import of food, and also have serious social impacts as agriculture employs 40% of the population.

The already massive extraction of 'fossil' water from the Nubian Sandstone Aquifer and the North Sahara Aquifer is expected to increase, giving rise to a wide range of secondary problems. Furthermore, models suggest that groundwater recharge will decrease dramatically along the southern rim of the Mediterranean – by more than 70% until 2050. Algeria and Tunisia are also vulnerable to natural hazards such as floods and, together with Morocco, could also be partly affected by sea level rise.

Middle East

Most climate scenarios, for Egypt and the Middle East in general, agree that the sub-region will suffer significant decreases in water availability with shifts in precipitation patterns and increased evapotranspiration. This will affect vital crops of the region, such as rice, citrus fruits, sugar beet, which rely up to 80% on irrigation (e.g. Egypt, Lebanon, Jordan). A temperature increase of 3-4 degrees Celsius could cause a 25-35% drop in crop yields, according to FAO.

Snowfall and in particular snow cover in high mountains of the region (e.g. in Lebanon, Turkey) are expected to decrease dramatically with negative hydro-geological, ecological and economic consequences (e.g., for winter tourism and hydropower).

Box 7: Climate change in the Mediterranean region: Possible threats and responses, cont.

Competition for water within the region and across its borders may grow, carrying the risk of escalating already serious conflicts, violence and political turmoil.

The Nile Delta is particularly vulnerable to flooding from rising sea levels.

South-eastern Europe

In South-eastern Europe, economic activities that depend on water availability such as agriculture, tourism, industry and energy will be adversely affected. In the Western Balkans, where countries such as Albania, Bosnia and Herzegovina and Serbia depend on hydropower for electricity supply, decreases in precipitation and shorter periods of snow cover in mountains will further stress energy security.

Along the Adriatic coast, increasing risks of flooding, erosion, and land loss (due to storminess and sea-level rise) will threaten human settlements and coastal natural habitats, including major wetlands, vital for biodiversity.

Mediterranean countries of the European Union

In the Southern EU countries major drought episodes are projected to become more frequent with particularly intense summer droughts. This may be further exacerbated because of an increasing demand for water as a result of elevated temperatures. Worst hit will be Cyprus, Malta, Greece (mostly Crete, Peloponnesus, Attica and the Aegean islands), southern Italy and its islands and southeastern Spain with an increase in frequency and severity of droughts and water scarcity. Heat waves may seriously affect tourism as well as people's health and enhance energy consumption for cooling purposes.

The island states of the region (Cyprus and Malta), in addition to the currently experienced severe water scarcity, are also particularly at risk from sea level rise and a number of sites, including valuable biotopes, are within a high vulnerability index.

Ecosystems

Many scientists and conservation experts expect climate change will have severe, detrimental effects on the coastal biotopes of the region. Wetlands especially, which constitute important buffer zones for water quality and flood prevention, are under immediate threat due to reduced water availability, further water abstraction and aggravated evaporation due to higher temperatures.

The impact of the reduced ecological services of wetlands goes far beyond the regulation of local water balances and protection of aquifers from salt-water intrusion. For instance, the drastic reduction of the size of the Nile plume outside its delta not only has changed the nutrient balance in the region and the stocks of prevailing fish species, but also has dramatically reduced the low salinity barrier at the entrance into the Mediterranean from the Suez Canal. The 'barrier' used to inhibit the entry of alien species from the Red Sea and the Indian Ocean but now its efficacy has been greatly impaired.

Box 7: Climate change in the Mediterranean region: Possible threats and responses, cont.

On a different front, Mediterranean forests and macchia plant-cover, due to reduced humidity, are more exposed to wild fires, thus reducing the vegetation cover. This development in turn accelerates land degradation and soil erosion in arid and semi-arid areas and leads to further release of greenhouse gases.

Throughout the Mediterranean there are hundreds of thousands of small and big dumping sites and landfills. Increased floods will increase pollution of surface and ground water bodies from leakages, while increased forest fires will result in higher atmospheric pollution by substances dumped and burned, taking into account that many of the illegal landfills are in the vicinity of forests.

Water-related adaptation responses for the Mediterranean

To some extent, resilience with regard to climate change impacts on water will depend on the state of water infrastructure. But as important are the institutional mechanisms that ensure promotion of ecosystem services and water demand management, which are often cheaper and more effective than the infrastructural approach.

Indeed, in the Mediterranean, all analyses agree that when addressing water shortages, priority should be given to managing demand over increasing supply, notably by introducing new and more efficient technologies, by adjusting prices, as well as by systematically informing, educating and promoting a culture of conservation in view of the declining water availability in the region.

Policies, strategic planning and institutional approaches

Adaptation to climate change will increasingly presuppose mainstreaming of policies, strategies and measures at all levels, including national, river basin and regional. This includes a range of activities, from responses to damage and disasters due to climate change to proactive policies aimed at reducing vulnerability.

Using higher ‘margins’ in all water calculations and previsions may be advisable in water and sustainable development planning. Some countries have already made important efforts in this direction, such as Morocco with its successful *National Human Development Initiative*.

To ‘climate-proof’ the water sector, adaptation tools, such as climate scenarios, vulnerability assessments, priority adaptation options and climate risk management schemes could be used extensively to facilitate decision-making at all levels. Developing inter-institutional cooperation would also constitute a useful step. Land-use planning *inter alia* for civil protection (i.e., relocation of communities at risk in frequently flooded coastal areas or river plains) and in particular careful designing of water infrastructure are all particularly useful tools.

Adequate regulatory frameworks will need to be developed and enforced; the institutional set-up might also be reformed so as to respond to emerging climate risks in a holistic approach. The

Box 7: Climate change in the Mediterranean region: Possible threats and responses, cont.

adaptive capacity of individuals as well as institutions and authorities needs to be enhanced.

Technical solutions

Water conservation and efficiency measures are of utmost importance for the protection of groundwater resources in particular. The relevant measures in this case should be closely linked to legal and socio-economic measures. They range notably from household water saving taps, water metering and economic incentives – e.g., block domestic water tariffs based on consumption levels – to the development of water-saving devices, leakage reduction in distribution networks, drip irrigation in agriculture, and cleaner production and recycling techniques in the industry and energy sectors. Already several countries offer incentives for drip irrigation and other water-saving devices.

Supply-side measures are also necessary to match the increasing water requirements of the people and the different economic sectors. Many of these measures are already widely applied and include the development of non-conventional water resources such as rainwater harvesting, applied in the region in various forms, reuse of treated waste water (to be promoted in the region for cultural purposes as 'regenerated' water), desalination techniques, as well as small- and medium-scale water collection and storage systems, large dam structures, sustainable drainage systems, inter-basin transfers and artificial groundwater recharge.

To ensure civil protection against climate-related disasters, contingency planning tools need to be developed region-wide and at country or area level. This implies strengthening hydrological monitoring capacities, development of early warning systems, civil protection mechanisms (i.e., fire-fighting equipment), drought management plans and flood risk mitigation schemes (i.e., strategies combining watershed management and land planning). Climate proofing of water infrastructure (i.e., dams, water collection devices) is another aspect of climate risk management.

Author: Michael Scoullos, Chairman, Global Water Partnership – Mediterranean (GWP-Med)

3. CLIMATE CHANGE ADAPTATION THROUGH BETTER WATER MANAGEMENT

Policy makers need to appreciate the role of water as a primary medium through which climate change will have an impact on development, and to incorporate this appreciation into overall development planning and management. Likewise, it is important for water managers and water users alike to adapt to the unfolding future. An approach to water resource management is needed that can identify and address the challenges – and uncertainties.

The challenge of climate change mitigation is being addressed through a series of fundamental changes in the way that societies produce and use their energy. These start from the resources societies use to fuel their activities, the way that these are used and combined to generate power, through to the settlement patterns that societies adopt for their cities and the public transport systems. It extends to patterns of production, consumption and trade, all with a view to reducing the production of carbon dioxide and other greenhouse gases.

A similar approach is required in the use of water. The challenge of climate change adaptation can begin to be addressed through a series of fundamental changes in the way society manages and develops its water resources. Unlike energy, water is difficult to transport over large distances and patterns of its use are very localized, varying dramatically between and within countries.[47]

Apparently different sources of water are often related to each other through the water cycle. Plantation forests on hillsides may deplete groundwater in the valleys; excessive pumping of groundwater in one area may dry up streams nearby; harnessing rivers for hydropower may affect fish populations and fish-erfolks' livelihoods in estuaries downstream.

So water resources must be managed, and water used and reused, in a manner that reflects water's variability, uncertainty, scarcity and abundance and the interconnectedness between its users at different scales locally, regionally and globally.

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[47] For a discussion of the unique economics of the transfer and delivery of water, see 'Water and Sanitation: Challenge Paper for the Copenhagen Consensus 2008', by Dale Whittington with W. Michael Hanemann, Claudia W Sadoff and Marc Jeuland, (Copenhagen: Copenhagen Consensus Center, 2008).

A key goal must be to ensure that all water users and other stakeholders in their societies have information about the water challenges that affect them, knowledge of different approaches that can help them to adapt, and institutional and governance arrangements that allow them to do that. This will also ensure that water challenges are addressed in broader climate change and development strategies.

Most important however is to have clarity on the goals of water resource management – beginning with a focus on the achievement of basic water security. Beyond that, the challenge is to find ways through which water and its management can contribute to broader social and economic development in a sustainable manner.

3.1. Water security, a first objective and framework for adaptation

Given the many ways in which water is used to improve lives and livelihoods, and the manner in which it can wreak devastation, the achievement of water security must be a first objective. This challenge, already one which many countries are struggling with, is now being aggravated by the prospect of climate change whose impacts will be felt disproportionately by the poorer more vulnerable communities of the world.

Water security therefore lies at the heart of adaptation to climate change. Water security, defined as *'the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks,'*[48] is a minimum but realistic package. Risks will not be completely avoided, but will be kept at an acceptable level. Similarly, health and livelihoods will not be maximized, but water management will support the attainment of acceptable minimum levels of social development. The imperative of protecting the natural environment is implied, since in many cases health, livelihoods and protection from natural disasters depend on sustaining the natural environment.

So, while 'water security' does not address the greater social and economic goals that many societies aspire to, or the full spectrum of their environmental goals, it does envisage the conditions under which water will not be a barrier to the achievement of such goals.

It should also be noted that water security does not come solely from protecting and ensuring adequate availability of water as a resource. The protection,

[48] Grey and Sadoff (2007).

development and management of water resources, and the management and delivery of water services, are linked but distinct endeavours. Both are challenges of water security. Getting water safely and reliably from the source to users usually requires the construction of infrastructure and the ongoing intervention of service provider institutions, particularly in large urban areas. While the challenge of ensuring that those service provider institutions work effectively lies beyond the scope of this paper, it is clear that if the resource is itself inadequate, it will be more difficult to provide adequate services. If the water service is not designed to take account of the likely changes in climate, as well as other pressures on the water resource, it may well fail.

Given these considerations, it is urgent that adaptation efforts begin immediately because both the institutions that we establish and the infrastructure that we build today lock us into patterns of behaviour for many years to come. Unless we act now, we will miss opportunities to make it easier to adapt to the changes and thus ensure a more sustainable long-term future.

Furthermore, the achievement of water security is not a once and for all matter, particularly not in the face of climate change. It will require a systematic effort to sustain it, and to manage the impacts of climate change amongst all the other drivers that are putting pressure on water resources. Water security calls for both technical and institutional innovations, and can drive opportunities to improve service delivery as well as to generate economic activity. A good example of this is the case of Singapore. Singapore demonstrated how a country can go beyond the immediate imperatives of water security by adopting and aggressively implementing a comprehensive and coordinated approach to achieving – and leveraging beyond – water security (see Box 8).

3.2. Water security through integrated water resources management

If water security is to be achieved and sustained, approaches to water management must reflect the integrated nature of the water cycle by addressing different users, uses, threats and threatened resources. IWRM is such an approach. IWRM explicitly recognizes the need to structure and manage the inevitable trade-offs required in water management. It recognizes that one use affects others and that all depend upon the integrity of the resource base.

Box 8: Creative water reuse and harvesting give Singapore security

Singapore is a small, densely populated island nation off the coast of Malaysia. Although it is in a tropical rainfall area, the small surface area of Singapore means that it has limited water resources and has traditionally depended on supplies from neighbouring Malaysia. Demonstrating that drivers other than climate change are often of more immediate significance, Singapore's water security was threatened when Malaysia initiated a renegotiation of supply agreements implicitly suggesting that it might limit future supplies.

The Singaporean response to ensure water security was to invest in a strategy focusing on conservation, efficiency, innovation and reuse. One consequence of this has been that its water needs can now be securely met. As important, it has developed a significant technological capacity, which it is exporting to other countries.

> 'Driven by a vision of what it takes to be sustainable in water, Singapore has been investing in research and technology. Today, the nation has built a robust, diversified and sustainable water supply from four different sources known as the Four National Taps (water from local catchment areas, imported water, reclaimed water known as NEWater and desalinated water).

By integrating the system and maximising the efficiency of each of the four taps, Singapore has ensured a stable, sustainable water supply capable of catering to the country's continued growth.'[49]

Needless to say, through this approach, Singapore has systematically reduced its vulnerability to climate change. Indeed, it is even able to take advantage of extreme rainfall events, storing the rainwater in man-made coastal lagoons, which will reduce the amount of water that has to be desalinated – incidentally, reducing its carbon footprint.

To effectively adapt to climate change, better water management will have to include a combination of 'hard' (infrastructural) and 'soft' (institutional) measures and go well beyond what is normally considered to be 'water business.' Critically, climate change adaptation strategies may require major changes in the way agriculture, industry and human settlements in general are managed.

Neither the challenges that climate change poses for development nor many of the potential responses are particularly new. Many of them were first articulated on an international platform in 1992 at the Rio Earth Summit, which warned of the dangers and outlined a program of action that sought to address them in a manner that balanced the twin goals of addressing environmental protection and the development needs of the poor world. At the 1992 Summit, the approach of integrated water resource development and

[49] PUB, 'Four national taps provide water for all', web pages, http://www.pub.gov.sg/water/Pages/default.aspx. Accessed 13/11/2008.

management (later shortened to IWRM) was agreed upon as a way to address a range of environmental challenges while ensuring that the needs of people, particularly poor people, are effectively addressed.

Significant progress has been made since the Rio Summit in 1992, but it has been slow and patchy. Aside from a normal institutional resistance to change, this is also due to the reluctance of governments and individuals alike to divert resources from short-term priorities to address long-term concerns. But it is also because the underlying issues are complex and there is limited experience of the interventions proposed or how they will work in practice.

The approach proposed at the Earth Summit in Rio de Janeiro in 1992, reiterated in 2002 by the Johannesburg World Summit on Sustainable Development, and very broadly adopted as global good practice today, is IWRM.

It is worth considering in some detail the way in which Agenda 21, the final resolution from Rio, addressed the question of climate and water (see extract in Box 9). Not only does it provide a valuable historical perspective but also, more importantly, it is evidence of the difficulty of moving from problem identification to effective action, and of a general failure to take advantage of early warnings. Taken together with Agenda 21's recommendations for integrated water development and management (the first time these were formalized and agreed at global level), many of its suggestions are as valid today as they were nearly two decades ago.

However, the most important part of Rio's Agenda 21 as it relates to water was the focus it placed on the need to manage water on a more integrated basis. This involved not just bringing different user sectors together but also recognizing that apparently different water sources (rivers, lakes and underground water) were all linked through the water cycle, and that socio-economic development, whether the expansion of urban services or the growth of new industry, could have major impacts on water resources and could only succeed in the long term if supported by effective water resource management.

> The widespread scarcity, gradual destruction and aggravated pollution of freshwater resources in many world regions, along with the progressive encroachment of incompatible activities, demand integrated water resources planning and management. Such integration must cover all types of interrelated freshwater bodies, including both surface water and groundwater, and duly consider water quantity and quality aspects.

Box 9: Proposed Programme of Action to Review Impacts of Climate Change on Water Resources (Abstracted from Agenda 21)

G. Impacts of climate change on water resources

Basis for action

18.82. There is uncertainty with respect to the prediction of climate change at the global level. Although the uncertainties increase greatly at the regional, national and local levels, it is at the national level that the most important decisions would need to be made. Higher temperatures and decreased precipitation would lead to decreased water-supplies and increased water demands; they might cause deterioration in the quality of freshwater bodies, putting strains on the already fragile balance between supply and demand in many countries. Even where precipitation might increase, there is no guarantee that it would occur at the time of year when it could be used; in addition, there might be a likelihood of increased flooding. Any rise in sea level will often cause the intrusion of salt water into estuaries, small islands and coastal aquifers and the flooding of low-lying coastal areas; this puts low-lying countries at great risk.

18.83. The Ministerial Declaration of the Second World Climate Conference states that 'the potential impact of such climate change could pose an environmental threat of an up to now unknown magnitude ... and could even threaten survival in some small island States and in low-lying coastal, arid and semi-arid areas'. Increase in incidence of extremes, such as floods and droughts, would cause increased frequency and severity of disasters. The Conference therefore called for a strengthening of the necessary research and monitoring programmes and the exchange of relevant data and information, these actions to be undertaken at the national, regional and international levels.

Objectives

18.84. The very nature of this topic calls first and foremost for more information about and greater understanding of the threat being faced. This topic may be translated into the following objectives, consistent with the United Nations Framework Convention on Climate Change:

(a) To understand and quantify the threat of the impact of climate change on freshwater resources;
(b) To facilitate the implementation of effective national countermeasures, as and when the threatening impact is seen as sufficiently confirmed to justify such action;
(c) To study the potential impacts of climate change on areas prone to droughts and floods.

Activities

18.85. All States, according to their capacity and available resources, and through bilateral or multilateral cooperation, including the United Nations and other relevant organizations as appropriate, could implement the following activities:

(a) Monitor the hydrologic regime, including soil moisture, groundwater balance, penetration and transpiration of water-quality, and related climate factors, especially in the regions and coun-

Box 9: Proposed Programme of Action to Review Impacts of Climate Change on Water Resources (Abstracted from Agenda 21) cont.

tries most likely to suffer from the adverse effects of climate change and where the localities vulnerable to these effects should therefore be defined;
(b) Develop and apply techniques and methodologies for assessing the potential adverse effects of climate change, through changes in temperature, precipitation and sealevel rise, on freshwater resources and the flood risk;
(c) Initiate case-studies to establish whether there are linkages between climate changes and the current occurrences of droughts and floods in certain regions;
(d) Assess the resulting social, economic and environmental impacts;
(e) Develop and initiate response strategies to counter the adverse effects that are identified, including changing groundwater levels and to mitigate saline intrusion into aquifers;
(f) Develop agricultural activities based on brackish-water use;
(g) Contribute to the research activities under way within the framework of current international programmes.

Source: UN, Agenda 21, The United Nations Programme of Action from the 1992 Earth Summit, http://www.un.org/esa/dsd/agenda21/index.shtml.

> The multisectoral nature of water resources development in the context of socio-economic development must be recognized, as well as the multi-interest utilization of water resources for water supply and sanitation, agriculture, industry, urban development, hydropower generation, inland fisheries, transportation, recreation, low and flatlands management and other activities. Rational water utilization schemes for the development of surface and underground supply sources and other potential sources have to be supported by concurrent waste conservation and wastage minimization measures.[50]

While the concept of IWRM is contested in some circles in what has become, at times, an almost doctrinal debate, three key attributes of IWRM still commend it as the best approach to the challenges that climate change will bring to the world of water:

- It recognizes the holistic nature of the water cycle and explicitly seeks to engage in an integrated way the full range of sectors that use, impact or are impacted upon by water thus ensuring that the approach of one sector does not, through water, undermine activities in another.

[50] Agenda 21, 18.3.

- It recognizes that the establishment of effective institutions will be essential if the conflicts and trade-offs between different activities and interests are to be successfully and equitably managed.

- It is inherently adaptive. IWRM recognizes that approaches to water management will have to change as the other sectors of society change and that there can be no once-and-for-all prescription.

The principles of IWRM clearly align with the challenges to water management that climate change will exacerbate. But what does this mean in practice? How can water management policies and practices align to help communities, ecosystems and environments adapt to climate change? What will be needed to achieve this?

Institutionalizing adaptation

The primary focus must be ensuring that institutional frameworks for water management are working effectively. Water policies and practices must aim to build institutions, information and capacity to predict, plan for and cope with seasonal and inter-annual climate variability as a strategy to adapt to long-term climate change. And these institutions must be able to facilitate processes of social and economic change that involve significant tradeoffs.

In this context, institutions are not only formal organizations; indeed, it may be preferable if formal organizations emerge only once the key challenges and the key functions that have to be undertaken are known. Institutions must be seen more broadly, for example to include informal coordination activities, information gathering and collation, setting of rules through legislation or cooperation, and the monitoring and regulation of compliance with them. All these activities are important and can be launched at different levels even in the absence of formal organizations. Good management practices that are developed in user communities are more likely to be sustainable than rules imposed from outside by formal organizations.

To achieve the goals of water security and development, users and resource managers must be engaged in an interactive way that enhances their ability to cope with uncertainty and respond to challenges as they emerge. An integral part of better water management is to ensure that all water users have information about the water challenges that affect them and knowledge of different approaches that can help them to adapt. This will also ensure that the water challenges are addressed in broader climate change and development strategies.

Among the challenges that have to be managed by water resource institutions, particularly in countries whose water endowment is limited, are the tradeoffs that have to be made between various water uses. Perhaps the most immediate and controversial of these is the tradeoff between the security offered by increasing storage capacity to cope with floods and low flows and the impact of construction projects on people living in the area. While the societal benefit from increased storage can be huge, the impact in terms of livelihoods, social structures and the environment can be devastating. In many countries, there is an equally challenging tradeoff to be made between the needs of agriculture, which often directly sustains the majority of the population, and that of the urban economy, which creates wealth, albeit inequitably distributed.

Devising mechanisms to determine who should get what share, in times of plenty and in times of scarcity, is at its root a political issue and requires robust institutions to achieve outcomes that are accepted by all those involved. And, as the demand for water grows and pushes the limits of what can be provided, there are decisions to be made about the balance between the protection of the natural environment, and the livelihoods that depend upon it, and the requirements of other social and economic activities.

Given the role of water in almost all dimensions of social and economic life and its fundamental role in the environment, any change in the pattern of water use and management will affect a variety of stakeholders. While the goal will always be to find win-win synergies, there will almost always be trade-offs of some sort to be made, and the process by which these are made needs to be institutionalized.

Investment – both hard and soft

An important element of the approaches to water resource management that have evolved over the past few decades has been the recognition that engineering solutions, while vitally important and an integral part of any future approach, will not by themselves solve the world's water problems. There is a range of social, economic and political challenges that have to be addressed and a variety of 'soft' institutional instruments that can be deployed to complement 'hard' infrastructural solutions.[51]

IWRM promotes both 'hard' infrastructural and 'soft' institutional strategies. Indeed, it is the judicious mix of both hard and soft strategies that offer countries the best chance of coping successfully with climate variability and change.[52]

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[51] GWP, 'Investing in infrastructure: The value of an IWRM approach,' GWP-TEC Policy Brief 7 (Stockholm: GWP, 2009).

[52] Ibid.

Box 10: Putting water onto the climate agenda: A case study from Central Asia

The Central Asian region lies in a semiarid and arid zone, which has suffered natural water scarcity for many thousands of years. The deserts of Karakum, Kzylkum, and Muyunkum cover more than half the region. Also in the region is the Aral Sea, one of the world's best-known water-related environmental disasters.

Competition between nature and society – between environmental needs and the water demands of growing populations – is already acute, even before considering the possible effects of climate change. Thus climate change has the potential to put the brakes on future regional economic development as well as adversely affect the region's ecology and the well being of its people.

The main impact of climate change in Central Asia is expected to be a reduction in available renewable water resources. To adapt will require major changes in water consumption. Because the agricultural sector is the biggest water consumer (about 85 % of the region's water resources are used for irrigation), there is an urgent need to assess water demand for irrigation under the new regimes of temperature and aridity and to consider adaptations in crop mixes and on farm water saving measures.

One view is that climate varies gradually and there is no need to be worried – 'we gradually will adapt'. But decisions regarding the management and development of water resources are often very long-term and outcomes appear only after 10-20 years. This means that adaptive actions are needed now. Policy-makers, planning bodies and water managers are already addressing a number of issues:

- Short-term measures at the level of end user (farmer) to combat droughts by implementing water saving practices, changing crop patterns, etc.
- Long-term measures at the national and regional levels to promote rational water use and re-allocation, including new regulations for food security and water requirements.

However, urgent actions are still needed:

- To create public awareness about possible climate changes and impacts.
- To demonstrate possible ways for overcoming of these phenomena.
- To plan the main direction for future actions.

Key elements of public awareness that still have to be created include:

- Central Asia is a water scarce zone.
- Water, the basis for well-being, is the most vulnerable system to climate change.
- Since water is a basis for health, there will be new requirements for water quality standards.
- It is very important to know the absolute level of water scarcity, and even more important to understand the possible fluctuations in water availability.

Box 10: Putting water onto the climate agenda: A case study from Central Asia cont.

Some Central Asian countries are preparing for climate change through investment projects under the framework of the Kyoto Protocol's Clean Development Mechanism (CDM).

For example, the Uzbekistan Government appointed the Ministry for Economy as the National CDM body and approved a special Statute on the development and implementation of the investment CDM projects. According to the Statute, the projects proposed for implementation have to meet the following national criteria of sustainable development:

Economic:

- Reduction of energy and raw stock consumption per unit of output.
- Improvement of the production efficiency or natural resource utilization via introduction of cutting-edge technologies.
- Facilitation of private market sector development in the Republic of Uzbekistan.

Environmental:

- Promotion of environmental conservation and degradation prevention.
- Minimization of the natural raw stock consumption and waste production.
- Introduction of technologies focused on raw stock recycling and/or utilization of renewable natural resources.
- Mitigation of negative impacts on the environment.

Social:

- Promotion of employment growth and increase of actual revenue of population.
- Health-improvement of the personnel involved in the project implementation and the population living in the project implementation location.
- Raising the population's awareness on natural resource management issues.

It is evident from this list that water was not initially considered to be a major issue. Uzbekistan has only recently realized that many climate related problems will only be addressed through water management and its government recently published a call for all institutions involved to elaborate a climate change adaptation strategy focusing on water related actions.

Thus, while we know what to do to implement the Kyoto Protocol, in terms of real adaptation, we are only beginning.

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'Hard' Options

One way to manage the impacts of climate variability on water resources is through 'hard options' to capture and control water. These options range from large-scale dams to household water harvesting structures.

Other important waterworks include canals, tunnels and pipelines, which not only supply human demands directly but, less obviously, create linked systems that, by virtue of their multiple sources, suffer less variability, provide greater flexibility and therefore offer enhanced supply security. Equally, robust wastewater treatment and stormwater drainage systems contribute to the ability of communities to maintain their activities and protect public health during extreme weather events while reuse reduces overall demand.

'Soft' Options

Water managers' armoury to address variability and extreme events is not restricted to infrastructure. As important are the institutional mechanisms that help to deal with climate variability; to achieve goals such as water supply for people, industries and farms; and to protect communities from flooding while sustaining ecosystems. These 'soft' tools manage demand as well as increase supply, through water allocation, conservation, efficiency, and land use planning. These soft tools are often cheaper, and may be more effective, than their infrastructural equivalents and can certainly complement infrastructure to ensure that it works effectively. Thus, in addressing potential water shortages, as much attention should be given to managing demand as to increasing supply, by introducing more efficient technologies as well as simply promoting a culture of conservation. This will be particularly important in areas where overall water availability declines.

In many countries, this is already done in a rudimentary way. For instance, organized drought restrictions in agriculture during times of supply stress. Targeted technical interventions such as leak reduction programmes in municipal distribution networks can not only pay for themselves through water savings but also provide direct energy savings, which help to mitigate climate change.

Demand management to encourage efficient use also has huge potential. Well-off households can substantially reduce their consumption and farmers can usually get far more 'crop per drop'; industrialists often achieve more production per unit water when put under regulatory pressure and can also locate water intensive processes in areas where water is plentiful. Incentives for water users to exchange their current water allocations, either through administrative systems or 'trading', can help to achieve more efficient water use, although the social impacts need to be carefully managed.

At a larger scale, the global trade system has a substantial impact – positive and negative – on water use, which needs to be understood and engaged. In this context, as has already been noted, the promotion of biofuels as a source of energy could greatly aggravate the challenges of water scarcity if not carefully planned and regulated.

Beyond direct water management, institutional instruments such as land use planning can substantially reduce the vulnerability of communities to water based natural disasters if they are informed by reliable flood data. This demonstrates that there is often a choice from a suite of hard and soft instruments that can be applied to enhance resilience. Thus resilience against floods can be achieved by building protective infrastructure or through planning that restricts settlement in vulnerable areas.

Urban planning can also contribute in other ways. Although rapid urbanization is often perceived as an environmental problem, it also brings environmental benefits. One of these is that household water demand is usually less in dense urban areas than in more thinly populated areas, not least because less water is used for gardens. Planning and building compact cities may indeed prove to be one of the more effective ways of curbing domestic demand of water.

Balance and sequence

In virtually all circumstances, water security will require a mix of investments in both hard (infrastructure) and soft (institutions) options. The right mix will be a function of many hydrological, economic, socio-political and environmental factors. Historically, when stocks of hydraulic infrastructure are low, investments in (man-made and natural) infrastructure have provided relatively higher returns. Investment in management capacity, and infrastructure operations and institutions become increasingly important as larger and more sophisticated infrastructure stocks are built (see Figure 6).[53]

The increased intensity of extreme flood and drought events suggests that climate change will enhance returns to infrastructure investments that allow water managers to control, store and deliver water under 'flashier' conditions.

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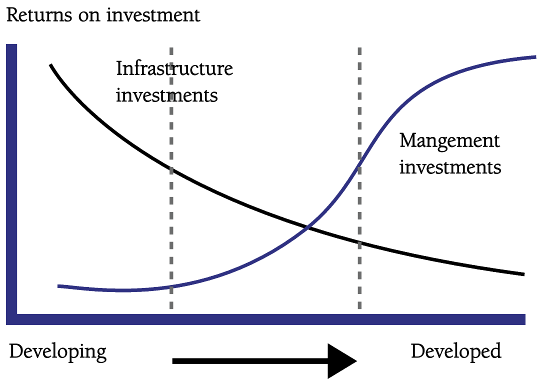
[53] David Grey and Claudia W. Sadoff, 'Water for Growth and Development' in *Thematic Documents of the IV World Water Forum*. (Mexico City: Comision Nacional del Agua, 2006).

Figure 6. Balancing and sequencing investments in water infrastructure and management



Source: World Bank, 'China Country Water Resources Assistance Strategy,' 2002.

On the other hand increasing variability and hydrological uncertainty suggest that the value of information and flexible, adaptive management institutions will be significantly enhanced.

Different elements should be introduced in an appropriate sequence. New allocation systems cannot be introduced before the additional water to be allocated is made available, perhaps by building storage. But before that can happen, there must be sufficient information about the resource to enable effective and sustainable storage to be designed. The appropriate mix and sequence will also need to reflect the related challenges of getting the right balance between equity, economic efficiency and environmental sustainability.

Information and infrastructure design

There is a real danger that the current generation of infrastructure investments will not cope with future challenges. Evidence suggests that some existing infrastructure will no longer be viable and might be best redesigned or decommissioned. Where precipitation is significantly diminished, existing irrigation reservoirs and hydropower dams may no longer be able to deliver the same volumes of water – and hence benefits – for which they were conceived and designed. On the other hand if rainfall significantly increases, infrastructure risks being overwhelmed, potentially resulting in burst pipelines and overtopped reservoirs. A longer run challenge is that existing design standards are no longer applicable to the conditions of the future.

Hydrological design parameters need to reflect the risk of climate change-induced variability. To make progress on this front means rehabilitating hydrological monitoring infrastructure and recovering existing data and acquiring new data. Unless a start is made to rebuild the basic systems to provide information about water resources, the danger is that new dams will not yield the expected water or power and that new water allocations will turn out to be 'dry'.

Beyond the immediate and obvious challenge of providing information to ensure that infrastructure is adequately designed, the wider challenge is to monitor trends in water availability and water use. If successful adaptation depends on increasing water efficiency in agriculture, water use and farm output have to be monitored. If there is concern about the impact of urban wastewater on river quality, the expansion and performance of water treatment facilities need to be monitored and a check maintained on river quality.

At present, monitoring is patchy and tends to focus on hot spots so that it is difficult for trends to be established before crises emerge. Systematic action is needed to address this gap. As a start, countries are being encouraged by the United Nations Statistical Division to begin to undertake 'water accounting' as part of national accounting systems. As UNSD points out:

> Only by integrating information on the economy, hydrology, other natural resources and social aspects can integrated policies be designed in an informed and integrated manner. Policy makers taking decisions on water need to be aware of the likely consequences for the economy. Those determining the development of industries making extensive use of water resources, either as inputs in the production process or as sinks for the discharge of wastewater, need to be aware of the long-term consequences on water resources and the environment in general.[54]

Taking actions at all levels

One of the challenges of water resource management is getting the right actions to happen at the right level. At the project level, water investments should be designed for resilience to climate change. At the village level, interventions should seek to diminish social, economic and environmental vulnerabilities to climate. Economy-wide planning should take account of climate shifts and the implications these might have for specific sectors or spatial areas. Globally, promotion of trade in water intensive products (virtual water trade) and targeted technology transfers could promote adaptation.

[54] UNSD, 'System of Environmental-Economic Accounting for Water,' Final Draft, New York 2009.

Box 11: Difficult tradeoffs: The Case of Southern Africa's Kavango River

The climate change induced reduction in the flow of the Kavango River is expected to be far greater than that from any current proposals for alternative uses of the Kavango's waters, which are unlikely to exceed 5% of current flows. The challenge for policy makers is whether to oppose any new abstractions on the grounds that the Okavango Delta wetland is threatened or to recognise that change will occur regardless, and allow for some additional human use as part of adapting to a changing environment.

While wetlands do absorb pollutants and moderate flood flows, these eco-system services can come with substantial opportunity costs. In the arid climate of Botswana, the entire flow of a river about the same size as the Orange is used simply to sustain its ecosystem. The water that enters the Okavango inland delta simply evaporates away while the Orange supplies most of South Africa's economy, with enough water left over to sustain riverine agriculture and a wetland at its mouth.

Because of the Okavango's RAMSAR status and its importance to Botswana as a tourist attraction, there has been vigorous opposition to proposals from neighbouring Namibia to take a small proportion (2%) of the annual flow of the Kavango for human and agricultural use. There is also concern about possible exploitation of both the agriculture and hydropower potential in the sparsely populated Angolan part of the river catchment, from which the vast majority of the river's water comes. Recent studies suggest however that: 'Implementation of all likely potential formal irrigation schemes mentioned in available reports is expected to decrease the annual flow by 2%.' The report states however that 'The simulated impacts of climate change are considerable larger than those of the development scenarios' with annual flows projected to be reduced by up to 26% by the period 2070-2099.[55]

In an already arid region, Namibia will face grievous challenges if climate change reduces regional rainfall, as is predicted and some accommodation will have to be found between the needs of people and those of the Okavango wetland ecosystem which will anyway shrink 'naturally' as a result. An appropriate response would be to share the burden between all three countries – Namibia, Botswana and Angola – allowing some abstraction even at the cost of some limited, additional shrinkage of the wetland. An institutional mechanism will be required to facilitate this process but it will only be effective if there is recognition of the principle that no single water use – environmental, social or economic – is sacrosanct and acceptance of the fact that tradeoffs will be needed.

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[55] Lotta Andersson, Julie Wilk, Martin C. Todd, Denis A. Hughes, Anton Earle, Dominic Kniveton, Russel Layberry and Hubert H.G. Savenije, 'Impact of climate change and development scenarios on flow patterns in the Okavango River,' *Journal of Hydrology,* Volume 331, Issues 1-2, 30 November 2006, pp. 43-57.

The impacts of variability, aggravated by climate change, are felt at different levels and have to be addressed at different levels. Individual farmers have to take decisions on what crops to plant and when – and need information to do so. Power companies need to know where their supplies are likely to come from and plan accordingly. And urban residents will demand that the decisions made on their behalf can allow a reliable supply for domestic and commercial purposes to be maintained. Ideally, effective decision-making processes will be 'built in' to the institutions that are established to manage water.

The very different impacts of climate change in different places mean that there cannot be a single prescription for action.

Still, trade-offs are inescapable

The hard reality is that climate change will force many trade-offs. As is clear from the outline of the interaction between water and climate change given above, there are no quick fixes for individuals, communities or societies that seek to adapt to the uncertain future that climate change is going to bring.

Whether it is constraining domestic water use to reduce pollution of already stressed rivers, taking water currently used by wetlands or cutting back on hydropower production to increase the reliability and sustainability of urban water supplies, tough choices will have to be made (see Box 11).

3.3 Adapting IWRM for Adaptation

Climate change is going to require a re-examination of current approaches in water management, as well as in the design of many components of urban settlements and economic and social infrastructure generally. In this context, lessons from the past and from areas that currently suffer from extreme conditions may be valuable. While water management is always driven by local contexts, there are several areas of effort that will clearly require renewed and increasing attention in all countries.

Disaster risk management

Intelligent and adaptive responses will depend on a systematic understanding of the potential risks and impacts of climate change and their application to specific situations. In this area, the expertise of hydrologists and engineers will need to be brought more closely together with that of risk managers in the insurance industry, disaster management specialists and regional planners. While this has begun to happen in some areas, countries and specialized agencies will need to promote such interaction in a systematic manner with the aim of identifying new and changing risks, prioritizing them in terms of likely impact and occurrence, and devising strategies to reduce them.

A special case of the institutional challenge is the integration of disaster management systems with the broader institutions of water management. Much knowledge about managing extremes already resides in specialized disaster management institutions. Based on the assumption that once rare events will occur more frequently, this knowledge will have wider and more general applications.

In the process of adaptation, many of the challenges are social as well as technical and institutional. Politicians need to be convinced of the nature of future problems before they are willing to devote time and resources to them. Behaviours need to be modified at community level if risks that have been identified are to be averted. Recent experience in the management of severe flood events has highlighted that the pre-emptive engagement of disaster management works before an extreme event, to ensure that communities are informed about risks and aware of how to respond to extreme events, has proved to be the difference between misfortune and calamity (see Box 12).

Information and cooperation

As already stated, managing increasing uncertainty and systemwide hydrological variability will increase returns to information and cooperation in water management at all scales. In this context, the need for information must increasingly be emphasized.

While theoretical estimates of likely events and patterns of occurrence can be made, it will be increasingly important to monitor trends in order to decrease uncertainty and achieve greater efficiency in interventions.

Currently, reliable information about actual water uses is limited and patchy. Thus while urban utilities can report in some detail about the volumes they produce and distribute, their figures do not include other sources of water (for instance wells and boreholes) which may be important for certain urban communities. Agricultural water use is often estimated from historic surveys making it difficult to assess current levels of use and changes in efficiency. Water quality is even more difficult to assess, particularly since, in many jurisdictions, polluters have an incentive not to share their data, for fear of prosecution.

The 'water accounting' process is an important start. While few countries are yet able to compile complete water accounts, the growing pressures imposed

Box 12: The lessons from Mozambique's millennial floods

The Mozambique floods of 2000 resulted in the death of more than 700 people, left tens of thousands of people homeless and destroyed much economic infrastructure. However, although this was caused by a unique combination of extreme events, far worse impacts were averted by the cooperation between disaster management authorities and water managers. Together, they were able to predict much of the impact and take measures to protect vulnerable populations.

The challenge they faced was a combination of technical, social and political. Among the conclusions:

> Modelling, supported by ground and satellite data, is a vital input to accurate short-term flood prediction. With the exception of the Limpopo, none of the country's river basins had calibrated models in place. Accurate prediction is in turn a prerequisite not only for the credibility of warnings to the public but also for the faith placed in the early warning system, and hence the resources allocated to it, by politicians.

Source: Flood management in Mozambique, (in) Hellmuth, M.E., Moorhead, A., Thomson, M.C., and Williams, J. (eds.) 2007. Climate Risk Management in Africa: Learning from Practice. International Research Institute for Climate and Society (IRI), Columbia University, New York, USA.

by climate change provide one more incentive for further action in this area. And it is recognized that, to achieve an accurate picture of a national water situation, partnerships will need to be built and strengthened between water managers and water users.

Water quality

Climate change will require greater focus on water quality dynamics. The IPCC reports with high confidence that higher water temperatures and intensified floods and droughts will affect water quality and exacerbate many forms of water pollution. In part this will be a consequence of the simple fact that rivers with less flow are less able to dilute and remove pollutants. Floods will move water across landscapes, picking up additional sediments, pathogens and pesticides. Salt-water intrusion is another water quality challenge that will be aggravated by climate change.

Understanding these dynamics will be critical to avoid harm to ecosystems, human health, and water system reliability and operating costs. This is another dimension in which the capacity of water resource managers will have to be strengthened.

Water rights and allocation mechanisms

With increasing extremes and unpredictability, water rights and allocation mechanisms are an area that will require serious review by policy makers and water managers. Water rights and allocations are generally premised upon historical water availability. As climate change causes future water availability to diverge from the past, the resource may no longer be able to conform to its agreed distribution. Past rights and mechanisms may no longer be viable. Systems of water rights, allocation and conflict resolution mechanisms will need to be put in place or strengthened to deal with these new realities. Flexible systems will need to be developed to respond to extremes of water availability and unpredictability.

While it is often suggested that water pricing and trading offers the best mechanism to allocate water between users in changing circumstances, this often fails to take account of the long-term nature of water uses and the challenges of, and limited opportunities for, moving water from one group of users to another to deal with short term variability. During the recent multi-year drought in Australia's Murray-Darling Basin, economic damage was limited by the way water was prioritized between users in their water allocation system.

A particular challenge for countries where water availability is expected to decrease under climate change will be to find mechanisms to adjust existing water rights. While trading can indeed be of some assistance, what is more important is that water allocation systems recognize that they operate in an environment in which the amounts of water available are going to change and that they establish rules for dealing with those changes.

South African water legislation does this by limiting the length of time for which water use permits are allocated to a maximum of forty years. It also provides for basin-wide allocation reviews every five years, if required.[56]

Where this kind of regular review is not provided for, difficult situations may emerge. Thus, in Australia, it is generally agreed that, even before considering any impacts of climate change, water abstractions need to be reduced to provide adequate water for ecosystem protection. In the absence of other mechanisms, the federal and state governments are being forced to consider expensive programs to 'buy back' allocations and compensate existing users for the loss of some of their water.

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[56] Government of South Africa, National Water Act 1998.

Rethinking water storage, transfers and reuse

Climate change will impact not only the volume of water storage that is appropriate, but also the appropriate type of storage (natural, man-made, small, and large.) Discussions of storage tend to focus on large-scale man-made dams but there is a range of storage options. These include natural storage, such as groundwater (naturally or artificially recharged), wetlands and lakes, and man-made storage at all scales, including household rainwater harvesting, traditional community tanks, small dams and weirs, and large-scale reservoirs.

In addition to natural and man-made storage of water, 'virtual' and 'financial' mechanisms can be constructed to 'store' the benefits of water. Water storage is essentially a hedge against the loss of benefits incurred when water is unavailable. Strategic grain reserves can be seen as stores of embedded water, amassed during high production years and redistributed during low production periods. Weather and crop insurance schemes can be seen as financial storage mechanisms that insure agricultural incomes by financial means, rather than insuring agricultural outputs through the enhanced reliability of irrigation (i.e., greater volumes of irrigation water under command.) Where water storage is desired to enhance the reliable delivery of water-intensive goods (agricultural or manufactured), trade in water-intensive products or 'virtual water' can be seen as an important alternative to actual water storage.

The comparative advantages and disadvantages of different types of storage will change as climates changes. Options that were once undesirable or unnecessary could soon become good options. What were good options in the past may not be in the future. New storage may be needed; some existing storage may no longer be viable. In some cases infrastructure could be modified to adapt to changing conditions, i.e., by providing additional intakes at lower reservoir levels in hydropower dams or changing the way in which the infrastructure is operated. In other cases decommissioning might be the rational alternative while reuse of wastewater will become more important. It is essential to revisit the range of infrastructure options in this new context, and reassess relative benefits and harms.

Another dimension of this is the possibility of transferring water between different catchments. In a situation of increasing variability and growing pressure on water resources, the ability to transfer water from one catchment to another can be attractive, particularly where demands of urban areas and key economic sectors are growing rapidly. Thus China has embarked on a massive transfer of water from the Yangtze to the Yellow river basin, and similar schemes are the subject of intense debate in countries as diverse as India, Australia and Spain. Countries such as South Africa, Mexico and the USA already make extensive use of such transfers.

Transfers can allow the distribution of water from one area to another. As important, they increase the reliability of supplies, and therefore the resilience of the systems, since different catchments typically have different patterns of variability. This contribution of enhanced resilience is likely to make inter-basin transfers more important under climate change scenarios if the environmental challenges to their application can be addressed.

Avoiding fragmentation

Given the great uncertainty and the challenges of collective action, neither adaptation nor water resource management can be treated as 'once-off' projects. They are about building dynamic organizations that have the tools and the ability to respond strategically and effectively to changing circumstances. To achieve this, managers in affected sectors as well as policy makers must be engaged to develop common understandings of and appropriate responses to the challenges.

Since water is only one factor in social and economic development, its management must be linked with broader planning and development efforts. In countries where there is a national development planning process, ensuring that water managers engage in it effectively is vital. For this to occur though, it is equally important that economic policy makers and those from other key water-using sectors are aware of the need to engage on water issues. [57]

There is a danger that water resource management efforts will be sidelined by a focus on adaptation planning. The general policy recommendation is thus that, while focused effort may be required to identify and initiate adaptation strategies, these should be integrated with – rather than run parallel to – ongoing water resource management work. Both need to be effectively mainstreamed into broader national development strategies, and special processes should be avoided, particularly in the context of development aid.[58]

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57 Mike Muller, 'How to integrate IWRM and national development plans and strategies,' GWP-TEC Policy Brief 6 (Stockholm: GWP, 2008).

4. FINANCING ADAPTIVE WATER RESOURCE MANAGEMENT

Although every international water meeting since Mar del Plata in 1977 has emphasized the importance of water resource management, it has been acknowledged that financing for water resources management has not received the attention it deserves. This makes it difficult to assess what additional allocations will be needed to strengthen existing water resource management activities so that they can address the challenges of climate change together with the other more immediate pressures that have been highlighted.

The Task Force 'Financing Water for All,' which was established by the World Water Council, the Global Water Partnership and the Secretariat of the 4th World Water Forum to maintain the momentum of the Camdessus Panel, addressed primarily the financing needs of agriculture and local governments but noted that:

> The river basin is the unit for management of spatial resources like land and water, and it allows looking at the full range of water resource management issues. The links and synergies between these different aspects are stressed in the Integrated Water Resource Management approach, which is rapidly gaining ground among policymakers. The creation of IWRM data, plans and coordination capacity itself needs proper funding. ***Some of the above mentioned functions are easier to finance than others, and for certain of them (e.g. provision of 'public goods' such as flood control and data collection) public funding will be necessary. The various constituent parts of water for agriculture should hang together financially.***[59]

Similarly, it was reported that progress in developing and implementing the IWRM plans called for in the WSSD's Johannesburg Plan of Implementation has been patchy. A key challenge that has emerged is the financing of the activities proposed and it was recommended to the Commission on Sustainable Development (CSD 16) in 2008 that: 'Countries should establish roadmaps and financing strategies for the implementation of their plans with External Support Agencies (including the UN, donors and NGOs) providing support to countries, based on demand.'[60]

[58] Tom Mitchell, Simon Anderson and Saleemul Huq, 'Principles for Delivering Adaptation Finance,' Institute of Development Studies, 2008.
[59] Winpenny, 2003.
[60] UN-Water. 'Status Report on IWRM and Water Efficiency Plans for CSD16,' 2008.

From these sources, two consistent messages emerge: first, that the integrated management and development of water resources is an important activity; second that its funding needs and the financial strategies to meet them have not yet been adequately addressed. In response to this gap, and driven in part by the challenges of engaging in climate change policy debates, work has now been initiated to identify financial needs and appropriate sources of finance for IWRM.

Historical neglect of financing strategies for water resources management is due in large part to the global focus in the water community on the short-term, immediate poverty priorities such as basic water supply and sanitation, and 'bankable' activities such as hydropower and industrial water supply.

In many poorer countries, capacity to manage water resources suffered during years of structural adjustment in which public sector expenditures were reduced. Often, it was the water resource management and hydrology functions that suffered most since the short-term priority was to provide water supply and sanitation. One consequence of this is that many countries cannot even manage their current climate variability, not because the strategies needed are unclear but because the means to implement them are lacking. They frequently ask why they should address tomorrow's climate change if they cannot afford to manage today's drought.

To date, discussions in the global processes to develop effective responses to climate change have been heavily weighted towards the challenge of mitigation. This reflects the strong sense that the immediate priority is to take action to reduce the extent of human induced change. As it becomes obvious that substantial change is very likely to occur, more attention is being given to adaptation.

To address adaptation, it is necessary to address the burden of adaptation financing which will fall more heavily on poor countries that are less resilient to start with. Africa and South Asia in particular will see some of the most extreme changes, and will have to meet these challenges with some of the world's weakest capacity. Even where the extent and scope of climate changes are similar, countries and communities with the institutions and capabilities to manage water resources will suffer less impact than those without.

For this reason, resources need to be mobilized to finance adaptation action. This is increasingly accepted and serious negotiations are ongoing. The adaptation financing landscape is changing rapidly and this paper is not intended to make specific recommendations about the processes underway.

Box 12: The costs of climate change for sub-Saharan Africa's cities

The costs of adapting existing urban water infrastructure in Africa have been estimated at between US$ 1,050 million and US$ 2,650 million annually:

Urban water storage US$ 500–1,500 million (capital cost)
US$ 50–150 million (annual equivalent)
Wastewater treatment US$ 100–200 million annually
Electricity generation US$ 900–2,300 million annually
(This does not include the cost of rehabilitating deficient infrastructure.)

The costs of new development are also likely to rise by between US$ 990 million and US$ 2,550 million annually. In general, the marginal unit cost of water resources development for water supply to urban areas increases with each new increment of supply. It is therefore conservative to assume that the costs of adapting to climate change for new developments will be similar to those for existing systems:

Urban water storage US$ 150–500 million (capital cost)
(New water supplies for 150M) US$ 15–50 million (annual equivalent)
Wastewater treatment US$ 75–200 million annually (assuming an additional 100M served)
Electricity generation US$ 900–2,300 million annually (assuming installed capacity doubles)

There are many other costs that will be imposed on urban areas through the water cycle. The economic impacts of rural water shortages on urban areas are particularly difficult to quantify. However, urban migration is a management challenge for almost all African cities, and any declines in rural production will certainly have second-order impacts on city economies.

There will also be additional costs incurred in the construction of roads and storm drainage, from the loss of use of land that is threatened by floods, and for additional flood protection for existing settlements. These and other indirect effects are site-specific and less easy to cost on a regional level.

The issue of flooding highlights the fact that climate change may not always be negative, as the availability of land for urban settlement may be positively affected by a reduction in rainfall. However, if the frequency and intensity of extreme storms rise, flood lines may not change significantly in a drier future, which would counter any possible expansion of habitable area.

Source: Mike Muller, 'Adapting to climate change: Water management for urban resilience,' Environment and Urbanization 19, No. 1 (2007): 99-113.

The debate about the potential sources of funding should be underpinned by a better understanding of the way in which those funds need to be applied, a dimension that is sometimes ignored.[61] Some general principles have been set out for overall adaptation funding[62] which emphasize, amongst other things, the importance of ensuring that the interests of the most vulnerable groups are prioritized.

It is suggested that there are three basic principles that should guide the development of arrangements for adaptation funding, insofar as it affects water resource management:

- Since IWRM, considered the international good practice approach to water resource management, is inherently adaptive, any new funding arrangements should prioritize the provision of long-term core funding for it.

- Investments in infrastructure for water resource management often provide essential public goods in addition to specific water or power supply benefits and these should be reflected in funding arrangements.

- Because water resources do not respect administrative boundaries, special arrangements should be made to fund water management activities across boundaries whether at local, state or national level where this is necessary.

4.1 Core funding for water management is core funding for adaptation

The Paris Agreement on Aid Effectiveness should serve as a guide for funding adaptation in poor countries, avoiding special purpose, special interest instruments wherever possible. A recurring theme through much of the early work on both managing water and managing the impact of climate change has been about the need to 'mainstream' the activity into overall development planning and management.

The provision of sustainable ongoing funding of national water resources management capacity, institutions and infrastructure should therefore be seen as a priority for mainstream assistance. The aim should be to ensure that long-term capacity is built and retained in the institutions that are going to have to cope with the unfolding changes.

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[61] See for instance, S. Spratt, 'Assessing the alternatives: Financing climate change mitigation and adaptation in developing countries,' New Economics Foundation, 2009 available at: www.stampoutpoverty.org/climatefinancereport.

[62] Mitchell, Anderson and Huq, 2008.

While management institutions and systems may become increasingly self-sufficient as they evolve and as growing water use increases the potential to raise funds from water users, newly established systems in developing countries with relatively low levels of water use will normally require extended periods of public funding. And there will always be 'public goods' elements of water resource management that merit public support.

In this context, water resources management investments should be viewed as sustainable development financing that also delivers adaptation benefits. Multi-purpose projects such as hydropower development (which also offers both flood and drought benefits) provide opportunities to deploy mitigation financing with adaptation benefits. This sort of multiple bottom line investment must be further explored and should be promoted in the adaptation finance architecture.

Many elements of the business of water resource management have either public good or merit good characteristics. That is, they provide services that benefit the wider public rather than specific user groups or, to the extent that they benefit particular groups, that benefit is one that merits public funding.

The provision and sharing of information about water resources is a classic example of a public good. The more societies know and understand about their water, the more likely they are to be able to adapt to changes in its availability or other pressures on the resource. For this reason, there is a strong case to be made for providing increased budgetary support for water resource management institutions that focus on monitoring the resource, analyzing information, and engaging with the public to communicate its implications and develop appropriate response strategies.

Action to prevent flooding, whether by promoting better land-use zoning of areas vulnerable to flooding or by constructing flood protection or storage works is a typical merit good. While individual communities may benefit from reduced vulnerability to flooding, so too does the whole society since it does not have to carry the cost of flood disruptions and flood relief.

The financing of water resource management, and associated development, should recognize and provide for the merit good components of the work. In particular, since the benefits of water resource management very often extend for very long periods of time (centuries in the case of major flood protection works), appropriate funding mechanisms are required for these elements that will not be fundable using traditional project financing mechanisms. In this, water resource management shares the challenge of climate interventions more generally which are clearly merited in the long term but whose execution is not necessarily 'bankable'.

4.2 Transboundary funding – creating incentives for cooperative responses

To the extent that specialized adaptation funds are made available, they should look beyond single-country solutions to generate public goods and to promote cooperative transboundary river basin solutions. Adaptation financing should not promote single-country interventions where multi-country cooperative interventions may be more effective. The same applies to sub-national structures in federal situations.

Thus in some transboundary basins, the best climate change adaptation interventions for any individual country might lie in basin-wide information and monitoring systems, or in upstream infrastructure investments and/or operations in a neighbouring riparian country. While international finance for adaptation should be mainstreamed in countries in terms of current aid effectiveness agreements, mechanisms should also be developed to encourage countries to explore cooperative options, and to promote cooperative water management solutions between countries where appropriate.

In the Ganges River Basin, for example, there has long been discussion that the best opportunities to control floods and to augment low-season flows in India and Bangladesh (the downstream riparian countries) would be investments in river regulation and storage in Nepal (an upstream riparian).

The evolving system for adaptation financing, however, is entirely country focused. To promote first-best solutions, adaptation finance should be structured to promote basin-wide solutions. Incentives should be designed to encourage countries to explore cooperative options, and, where these prove most appropriate, seek to design cooperative adaptation responses.

It is also necessary to consider the trans-boundary issues at lower levels of administration. Many water resource management interventions are made at the level of the hydrological unit, which often cuts across administrative boundaries. This can greatly complicate financing arrangements and lead to sub-optimal investments where, for instance, two municipalities build separate storage works in the same catchment when a shared installation would be more cost-effective.

Innovative instruments to incentivize cooperation across boundaries are required as well as direct funding of inter-jurisdictional investments. These issues should be considered at both national and sub-national level (in federal systems) by current reviews of IWRM financing.

5. CONCLUSIONS

The long time horizons and great uncertainties associated with climate change call for adaptation responses that can deliver immediate benefits, while building robust, adaptive institutions designed to ensure enduring resilience. Investments in water resources management provide just this; they are, by nature, investments in adaption.

A focus on achieving and sustaining water security provides immediate benefits, particularly for underserved and vulnerable poor populations, as well as greater capacity to manage future risks. Today's investments in water security should be seen as an explicit part of a coherent longer-term strategy for adaptation that will build a more resilient world in the future.

Support to core water resources management information systems, institutions and investments – rather than fragmented 'climate proofing' water initiatives – aligns with best practice principles for aid effectiveness and provides a durable and efficient framework for achieving water security and mainstreaming adaptation efforts into national development plans.

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