Perspectives on water and climate change adaptation

Better water resources management – Greater resilience today, more effective adaptation tomorrow

This Perspective Document is part of a series of 16 papers on «Water and Climate Change Adaptation»

'Climate change and adaptation' is a central topic on the 5th World Water Forum. It is the lead theme for the political and thematic processes, the topic of a High Level Panel session, and a focus in several documents and sessions of the regional processes.

To provide background and depth to the political process, thematic sessions and the regions, and to ensure that viewpoints of a variety of stakeholders are shared, dozens of experts were invited on a voluntary basis to provide their perspective on critical issues relating to climate change and water in the form of a Perspective Document.

Led by a consortium comprising the Co-operative Programme on Water and Climate (CPWC), the International Water Association (IWA), IUCN and the World Water Council, the initiative resulted in this series comprising 16 perspectives on water, climate change and adaptation.

Participants were invited to contribute perspectives from three categories:

1 **Hot spots** – These papers are mainly concerned with specific locations where climate change effects are felt or will be felt within the next years and where urgent action is needed within the water sector. The hotspots selected are: Mountains (number 1), Small islands (3), Arid regions (9) and 'Deltas and coastal cities' (13).

2 **Sub-sectoral perspectives** – Specific papers were prepared from a water-user perspective taking into account the impacts on the sub-sector and describing how the sub-sector can deal with the issues. The sectors selected are: Environment (2), Food (5), 'Water supply and sanitation: the urban poor' (7), Business (8), Water industry (10), Energy (12) and 'Water supply and sanitation' (14).

3 **Enabling mechanisms** – These documents provide an overview of enabling mechanisms that make adaptation possible. The mechanisms selected are: Planning (4), Governance (6), Finance (11), Engineering (15) and 'Integrated Water Resources Management (IWRM) and Strategic Environmental Assessment (SEA)' (16).

The consortium has performed an interim analysis of all Perspective Documents and has synthesized the initial results in a working paper – presenting an introduction to and summaries of the Perspective Documents and key messages resembling each of the 16 perspectives – which will be presented and discussed during the 5th World Water Forum in Istanbul. The discussions in Istanbul are expected to provide feedback and come up with sug• gestions for further development of the working paper as well as the Perspective Documents. It is expected that after the Forum all docu• ments will be revised and peer-reviewed before being published.

4 Better water resources management – Greater resilience today, more effective adaptation tomorrow

A Perspective Paper contributed by the Global Water Partnership through its Technical Committee.

This perspective paper was prepared under the direction of the Technical Committee of the Global Water Partnership. TEC members Claudia Sadoff and Mike Muller served as lead authors, with additional inputs and commentary from the TEC Chair, other TEC colleagues and a GWP-wide working group on climate change adaptation.

The paper is the second contribution of a GWP programme of work to review different aspects of water use and management relating to climate change. It builds on Policy Brief 5, "Climate Change Adaptation and Integrated Water Resource Management – An Initial Overview", released in 2007, which has benefited from CPWC's publication «Climate Changes the Water Rules», and is intended as a preliminary articulation of the framework that GWP will utilize for its work on climate change adaptation under its new strategy for the period 2009–2013. The preliminary ideas and concepts outlined in this perspective paper will be further developed in a full TEC background paper on the subject to be published during 2009. The background paper will also provide examples and identify, through the GWP partnership network, some of the region-specific dimensions of the challenge and the particular interventions that are required at each level.

The paper complements a series of background papers and policy and technical briefs prepared by the Global Water Partnership through its Technical Committee. These publications can be downloaded from www.gwpforum.org or hard copies can be requested from gwp@gwpforum.org.

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Better water resources management – Greater resilience today, more effective adaptation tomorrow

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

Improved understanding of the dynamics of climate change as it affects water supply and demand and the broader impacts on all water-using sectors will guide better water resources management. This will in turn build resilience to current climate variability, while building capacity to adapt to future climate change. Water is recognized to be key to the achievement of many of the Millennium Development Goals. So better water resource management is a cost-effective strategy; delivering immediate benefits to vulnerable and underserved populations, while strengthening systems and capacity for longer-term climate risk management.

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

A water secure world will need better information and stronger institutions, as well as investment in infrastructure – small and large scale – to store and transport water. It will require balancing equity, environmental and economic priorities; and 'soft' (institutional and capacity) as well as 'hard' (infrastructure) responses. It will need appropriate attention to both natural and man-made storage options. It will require actions and innovations at all levels: in projects, communities, nations, river basins and globally. Integrated water resources management offers an approach to manage these dynamics, and a thread that runs up and down these levels of engagement.

Financial resources are needed to build a water secure world. Sound water management, which is a key to adaptation, is weakest in the poorest countries, those with the greatest climate variability today, and those predicted to face the greatest negative impacts of climate change. Investment in national water resources management capacity, institutions and infrastructure should therefore be a priority for mainstream aid, as well as for sustainable development financing that delivers adaptation benefits.

In some transboundary basins the best adaption investments for any individual country may lay 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.

1 Water resources 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; shifting rainfall patterns will affect cropping systems and the prevalence of vector-borne diseases such as malaria; 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 are growing around water-borne disease incidence, glacier melt, glacier lake outburst flood risks and sea level rise.

These impacts are the consequence of the way in which the hydrological cycle is expected to be affected by climate change. While in many cases, the impact cannot yet be proven, the long-term nature of water resource management means that responses need to start now. This will require enhanced understanding of water resources to inform well-directed management and investment interventions. The benefit will be that these interventions will also help to manage current climate variability and shocks, particularly in the world's poorest countries.

1.1 Water is a primary medium for climate change impacts

The Ministerial Declaration of the Second World Climate Conference states "...that among the most important impacts of climate change were its effects on the hydrologic cycle and on water management systems and, through these, on socio-economic systems." (Second World Climate Conference, 1990)

A 'leverage' effect could see relatively small temperature changes leading to a 10 – 40% increase in average river flows in some regions and a 10 – 30% decrease in others. This could have a major impact on water supplies to a rapidly urbanising world as well as on shelter and transport infrastructures. It may render many of the industries and much of the agriculture that supplies and feeds them highly vulnerable, if not unsustainable.

1.2 Proactive water management is proactive 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 resources.

In pursuing these changes, we suggest the end goal should be to achieve 'water security': 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 (Grey and Sadoff, 2007).[1]

To achieve water security, investments will be needed in infrastructure to store and transport water, as well as to build institutions that are armed with the information and capacity to predict, plan for and cope with climate variability. Such investments will help adapt to long-term climate change and manage current climate variability and shocks – thus offering water security to the world's poorest countries.

The art will lie in finding the right balance between the different kinds of intervention.

1.3 The role of Integrated Water Resources Management

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 programme of action that sought to address them in a manner that balanced the twin goals of addressing environmental protection and the development needs of poor countries. To help achieve these goals, the principles of the integrated water resource management (IWRM) approach were also agreed upon.

Agenda 21, the final resolution from Rio (United Nations Conference on Environment and Development, 1992), provides a valuable historical perspective as well as evidence of the difficulty of moving from problem identification to effective action. It highlighted that:

> *"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 fresh-*

[1] It is worth noting that this definition does not focus on security as relating to threats of violence or war, although some related concerns, such as the intentional contamination of water supplies, could be addressed as water-related risks. Nor, for the purpose of this paper, does it focus only on arrangements for the security of household level water services, though it does include those services.

water bodies, including both surface water and groundwater, and duly consider water quantity and quality aspects. 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 underwater supply sources and other potential sources have to be supported by concurrent waste conservation and wastage minimization measures."

These dimensions become even more important as we seek to understand how climate change factors into this already complex mix.

Two key attributes of IWRM commend it as an approach to the challenges of climate change. The first is that it integrates the activities of a range of sectors that use, impact or are impacted by water thus ensuring that activities in one sector do not undermine those in another. The second is that it recognizes that effective institutions will be needed to manage the trade-offs between different activities and interests (Global Water Partnership Technical Advisory Committee, 2000 and 2007).

2 Climate change challenges for water resource management

2.1 The physical science

While some regions may benefit from climate change, overall the IPCC predicts that the effects of climate change on water resources will have negative implications. The IPCC Technical Paper on Climate Change and Water (IPCC, 2008) states that:

*"**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)" [3.2.5]*

It is against this technical background that the challenges of the future have to be addressed, although it should be remembered that existing climates are already highly variable and climate change simply adds to the complexity and scale of the challenge of managing this variability.

While there is growing confidence about model predictions of changing temperatures and rainfall, the impact of these changes on water availability from rivers, lakes and underground sources is poorly understood. As an example, 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. Changes in aridity will have a substantial impact on both surface water runoff and groundwater recharge as will changes in the timing and intensity of rainfall.

The impact of global warming on snow fields and glaciers will also impact water resources, since they currently act as natural reservoirs, storing water in winter and releasing it gradually as melt-water in summer. Under global warming scenarios, the melting of snow and glaciers will first increase and then reduce river flows, causing first floods, then droughts. The phenomenon is particularly important in the Andean region of South America and the Himalayan region of South Asia.

Further complicating the picture will be the impact of climate change on vegetation cover which will in turn significantly change both runoff and evaporation. All these factors will affect the water resources available for use by societies.

Water quality effects are also important. Reductions in river flows will reduce their capacity to dilute wastes and require additional investments to achieve the same standards of environmental protection. 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 a further quality challenge.

The ability to monitor and predict such climate change impacts at a scale that is helpful to users is still extremely limited, leading the technical team of the IPCC working on water and climate (IPCC, 2008) to conclude that:

> *"There is a need to improve understanding and modelling of changes in climate related to the hydrological cycle at scales relevant to decision making."*

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, the quality of the hydrological data, which is needed to monitor the impact of climate change and to guide future planning, has generally deteriorated since then.

Much of the data on streamflows that is held by the Global Runoff Data Centre in Germany is more than 30 years old, and in 2008 support was terminated for the Global Environmental Monitoring System (GEMS), a worldwide repository of water quality data.

In many poorer countries, hydrological information systems decayed when scarce resources were allocated to more immediate needs, and even in the rich world, monitoring targets have often not been met. As a result, in many countries there is limited information to support the planning, development and management of water resources, a situation which cannot be reversed overnight.

2.2 The broader dynamics

Changes in the availability, timing and reliability of rainfall and the water resources that flow from it will have impacts 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 their achievement and their sustainability once achieved.

While the overall availability of water will not necessarily decrease with climate change, the distribution and timing of rainfall will change. This 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 variability of rainfall will also increase with climate change, and this will impact growth potential and the costs of achieving adequate levels of water security. In Ethiopia, the economic cost of hydrological variability is estimated at over one third of the nation's average annual growth potential (Grey and Sadoff, 2007).[2] Variability, in fact, 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.

As climate variability increases, so too does the cost of the infrastructure, information and systems needed to cope with it. The major impact of climate change in many sectors may be an increase in the cost of water services, and the cost of reliability in service delivery. This will not only be the case for drinking water, but also for agriculture, power production, services and 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.

Climate change will increase the incidence of catastrophic events such as flood and drought. This will impact lives, livelihoods, land values and investment incentives in vulnerable areas. While readiness and insurance schemes as well as water management interventions will be instrumental in addressing these risks, the prospects for these increasingly vulnerable areas will change. In general, more vulnerable areas are inhabited by poorer populations.

2 This estimate is based on the results of a stochastic, economy wide multi-market model that captures the impacts of both deficit and excess rainfall on agricultural and non-agricultural sectors. The results show growth projections dropping 38% when historical levels of hydrological variability are assumed, relative to the same model's results when average annual rainfall is assumed in all years (which is the standard modelling assumption) (Grey and Sadoff, 2007).

Those with options move away from hazards or uncertainties. 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, and even the structure of economies. 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.

2.3 Timeframes, sequencing and uncertainty

The uncertainty which pervades every aspect of climate change adaptation planning is seen by some 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.

However, implementing any new approaches to water resources management responses will also be a long-term process. Institutions take time to design and establish. Major water resources infrastructure, such as large reservoirs and canals, routinely take over a decade to plan and construct.

While sequencing and prioritizing specific medium-term priorities is surely complex, it is timely and wise to focus now on opportunities for enhancing management capacities, for strengthening information systems, and for building infrastructure to enhance resilience at both small and large scales.

3 Climate change responses through water resources management

Given the impending challenges, it is crucial for policy makers to recognize the role of water as a primary medium through which climate change will have an impact on development and to incorporate these considerations in 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 is analogous to the way that the mitigation challenge 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, although arguably water provides a greater challenge since, in many cases, it is sourced directly from the natural environment of which it forms part. Unlike energy, water is difficult to transport over large distances and patterns of its use are very localized, varying dramatically between and within countries. 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; overenthusiastic pumping of groundwater in one area may dry up streams nearby; harnessing river for hydropower may affect fish populations and fisherfolks' livelihoods in estuaries downstream.

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

3.1 Adaptation through better water resources management

If water security is to be achieved and sustained, it will require approaches that reflect the particular challenges of the water cycle, aggravated as they will be by drivers including, but not limited to, climate change. Such approaches should reflect the integrated nature of the water cycle by incorporating the different users, uses, threats and the threatened.

IWRM is an approach to water management that explicitly recognizes the need to structure and manage the trade-offs required, recognizing that one use affects others and that all depend upon the integrity of the resource base.

Better water management will be essential if communities are to adapt successfully to climate induced changes in their water resources. The strategies adopted will have to use a combination of 'hard', infrastructural, and 'soft', institutional, measures and to go well beyond what is normally considered as 'water business'. Critically, they will require major changes in the way agriculture, industry and human settlements in general are managed. The future resilience (or vulnerability) of human communities to climate change related impacts will depend, in large measure, on their success.

The patterns of water use as well as the nature of the water resource itself are dynamic and ever-changing. Changes in consumption patterns and production technologies, changing patterns of trade or political and social preferences and priorities all have an impact on the way water is used and the impacts human activities have upon it. Similarly, changes in the resource, including the impacts of anthropogenic climate change cannot be projected with any degree of precision, and institutions must be able to respond flexibly to the changes as they emerge.

A further important advantage of the IWRM approach is that it is itself adaptive. Properly applied, IWRM establishes institutions and processes that can identify and respond to changes in the economic and social environment as well as in the natural environment.

3.1.1 Institutionalizing adaptation in water management

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?

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. 'Soft' institutions – which include informal coordination activities, information gathering and collation, setting of rules through legislation or cooperation, and the monitoring and regulation of compliance -- are equally important. Good management practices that are inculcated in user communities are more likely to be sustainable than rules imposed by formal organizations.

To achieve the goals of water security and development, water challenges need to be addressed within broader climate change and development strategies and 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. In part, this means ensuring that all levels of decision-makers – from policy makers to water managers to users – have the information they need to develop and continuously update adaptation strategies.

While information and the capacity to understand it is essential, in many countries, the ability of core management institutions to address current let alone future challenges is limited and needs to be strengthened.

The same applies to another key function of water resources management, the facilitation of tradeoffs between different water users and uses to cope with both variability and long-term climate change. These tradeoffs need to balance the 'three Es' of economic

Efficiency, social Equity and Environmental sustainability.

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 usually be trade-offs of some sort to be made and the processes by which these are made (and the way negative impacts are mitigated) need to be institutionalized.

Thus tradeoffs have to be made between the security offered by dams, which increase water storage capacity to manage low flows and floods, and the impact of construction on people living in the project area. While the societal benefit from increased storage is huge, the impact in terms of livelihoods and social structures can be devastating.

There are also tradeoffs between different uses; in many countries the needs of farmers and hydropower generators are not aligned and assuring security of water supply to urban residents may reduce power generation income. 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 which requires robust institutions to achieve outcomes that are accepted by all those involved.

And, as the demand for water grows and reaches the limits that can be provided, there are decisions to be made about the balance between the protection of the natural environment of which water forms part and the requirements of social and economic activity. While the decisions themselves will reflect domestic political processes, water management institutions must help to frame and facilitate them.

3.1.2 Actions will need to take place at all levels (projects, villages, economy-wide, global)

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 into account climate shifts and the implications this 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.

The impacts of variability, aggravated by climate change, are felt at different levels and have to be addressed at all levels. Individual farmers have to take decisions – 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 need to know that reliable water supplies for domestic and commercial purposes will be maintained. Ideally, decision-making processes will be 'built in' to the institutions that are established to manage water.

3.1.3 Actions will need guidance by science and best practices from both water and climate fields

While many of the responses to water management challenges are as old as civilization, new circumstances create many opportunities – and many needs – for innovation and fresh thinking.

In many regions, rainfall and river flows are already extremely variable in both timing and amount, and it has been suggested that climate change will simply mean 'more of the same' variability.

To some extent this is correct. Variability is the stock in trade of hydrologists and water engineers who use well understood statistical techniques to estimate the variability of rainfall and streamflow. This is then applied to the design of infrastructure such as storage dams, flood protection dykes and even the culverts which ensure that roads are not washed away. The future may not however be amenable to being predicted in the same way.

Practitioners and publics alike will need to have access to the best possible information as well as to different approaches taken in different communities to ensure that they choose the most appropriate alternatives and are not trapped by their pasts into a dead-end future. In particular, it will be important to improve access to climate information and to develop stronger linkages with climate scientists, in order to take on board the significant recent improvement in the science community's ability to predict, with some degree of accuracy, climate variability at seasonal and inter-annual scales (Kabat et al, 2002). Incorporating this information effectively as part of water resource management could be a crucial tool for coping more effectively with climate variability and building capacity for adapting to climate change.

3.1.4 Actions must balance software (intelligent and robust institutions) and hardware (adequate infrastructure)

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. The art is in finding the right balance.

'Hard' Options

One way to manage the impacts of climate variability on water resources is through 'hard options' to capture and control river flows. Storage dams are built to retain and store flows that are in excess of user requirements and to release them during periods when low flows are not sufficient to meet user needs, a practice that can also serve to maintain aquatic ecosystems. Alternatively, during floods, peak flows can be stored for later release, avoiding flood damage by reducing maximum flows. Both functions are important to sustain urban settlements and to avert disasters caused by floods and droughts.

Dams also harness water as a form of potential energy to generate electricity, without which healthy urban life is difficult to sustain as settlements increase in size. Nineteen per cent of the world's electricity is currently generated from hydropower and there is substantial potential to expand this, particularly in low- and middle-income countries. A specific benefit of hydropower is that it does not usually generate significant quantities of greenhouse gases and thus allows economic and social development to occur without aggravating global warming.

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 and therefore offer enhanced supply security. Equally, wastewater disposal and stormwater drainage systems contribute to the ability of communities to maintain their activities and protect public health.

'Soft' Options

The armoury available to water managers for addressing variability and extreme events is not restricted to infrastructural means. As important are the institutional mechanisms that help deal with climate variability and achieve goals such as water supply for people, industries and farms, flood protection and ecosystem maintenance. 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 and 'hosepipe bans' for domestic users should be seen as institutional mechanisms used to manage variability by prioritizing different water uses at 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 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, 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. Thus resilience against floods can be achieved by building protective infrastructure or through planning which restricts settlement in vulnerable areas. This demonstrates that there is often a choice from a suite of hard and soft instruments that can be applied to enhance resilience.

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, for obvious reasons. Planning and building compact cities may indeed prove to be one of the more effective ways of curbing domestic use of water.

In all this, it is important to recognize that many of these challenges are not new and are certainly not the product of climate change alone. Thus, aside from urbanization, the changing lifestyles and dietary patterns associated with growing affluence in countries like China and India will, arguably, have an even greater and more immediate impact on the water environment. This is why it is important to address the impact of climate change on water resources as part of a broader programme of better water management.

Mixing 'Hard' and 'Soft'

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, investment in 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 (Grey and Sadoff, 2006) (see Figure 1).

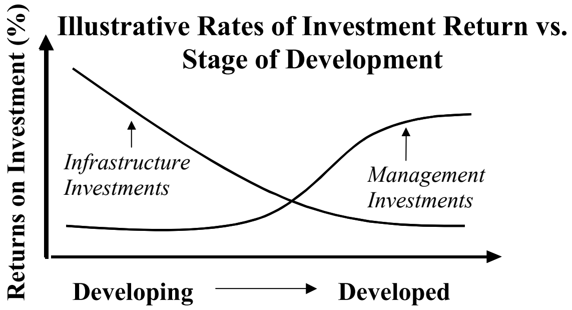

Figure 1: Water infrastructure and management. Source: World Bank (2002)

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 more variable conditions. On the other hand increasing variability and hydrological uncertainty suggest that the value of information and flexible, adaptive management institutions will be significantly enhanced. The right balance will be driven by specific circumstances, but returns to investments in both can be anticipated to rise.

3.1.5 Balancing the Three Es

In choosing between different strategies to address water challenges and in their implementation, it is clear that important political choices have to be made between different economic and social interests as well as about the impacts on the environment.

The approach adopted needs to ensure that these choices are made explicit and that the process followed achieves an appropriate balance between conflicting interests.

In the countries most threatened by climate change, particular attention will have to be given to ensuring that the voices of the poorer and more marginalized communities are heard since they will usually be the group most at risk, whether from hunger due to drought and crop failure or from the impact of floods and related disasters, which usually have their greatest impact along the river banks and ravines of crowded cities where the poor are more likely to live.

3.2 What's new in all of this for water resources management?

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.

3.2.1 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. The challenge is to extract this wisdom about dealing with extreme events and apply it more generally, on the assumption that once rare events will occur more frequently.

In this process, it will be recognized that 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 the loss of property and infrastructure only and the loss of lives.

3.2.2 Information and cooperation

Managing increasing uncertainty and system-wide hydrological variability will increase returns to information and cooperation in water management at all scales.

In this context, the need for information must be emphasized. As emphasized earlier, it will be particularly important to improve access to climate information and to develop stronger cooperation with climate scientists and take advantage of techniques to predict climate variability at seasonal and inter-annual scales. However, 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.

For this to occur, far greater investment will be required in both the physical (and remote) monitoring and the institutions needed to interpret the data and translate it into relevant information for policy and practice.

3.2.3 Water quality

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 rise with 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.

3.2.4 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, 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.

3.2.5 Rethinking water storage

Since hydrological variability will increase with climate change, greater storage will be needed to capture peak flows and augment low flows. This is essentially an investment in greater water security and reliability.

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 storage dams but there is a range of storage options, which includes natural storage, such as groundwater (naturally or artificially recharged), wetlands and lakes; and man-made storage at all scales, which includes household rainwater harvesting, traditional community tanks, storage dams (from small to large), 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 important alternatives to actual water storage.

The comparative advantages and disadvantages of different types of storage will change as climates change. 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, e.g. by providing additional intakes at lower reservoir levels in hydropower dams or changing the way in the infrastructure is operated. In other cases decommissioning might be the rational alternative.

It is essential to revisit the range of storage options in this new context and reassess relative benefits and harms.

3.2.6 Adaptive management

Given the great uncertainty and the challenges of collective action, flexibility and continuous strategic updating will be more crucial than ever before.

There are multiple challenges confronting communities and countries that seek to 'climate-proof' themselves, by managing their water resources more intelligently to increase their resilience to climate variability and thus to reduce their vulnerability to the effects of climate change. As always, poorer countries will face the greatest challenges. Addressing these challenges will require strong and well-informed leadership as well as effective strategies.

A key challenge is to orient water managers, as well as their partners in key water use sectors, to the potential impact of the emerging new climates. Intelligent institutions are needed at all levels – institutions that can go beyond managing water on a day to day basis to identify water use trends, areas vulnerable to climate change and opportunities to respond as well as possible to the emerging challenges.

This cannot be a one-off project. It is about building dynamic organizations that have the tools and the ability to respond strategically and effectively to changing circumstances. To achieve this, key water use sectors as well as policy makers must be engaged and share a common understanding of the challenges so that appropriate responses can be identified and supported, and trade-offs made.

3.3 Financing adaptive water resource management

The current global focus on water is on the short-term – immediate poverty priorities such as basic water supply and sanitation and 'bankable' activities such as hydropower and industrial water supply. Yet there is a real likelihood that without effective long-term water management these current activities will prove to be unsustainable. Hydropower plants are already failing to produce the amount of electricity expected; basic water supplies are failing for lack of adequate water sources; agriculture in many regions is making unsustainable demands on groundwater resources.

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 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 rightly 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.

However, it is important to address the burden of financing adaptation processes which will fall more heavily on poor countries which are less resilient to start with. Africa and South Asia in particular will see some of the most extreme changes and have some of the world's weakest capacity to deal with these changes. Even in cases 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 who do not.

For this reason, resources need to be mobilized to finance adaptation action. This is increasingly accepted and serious negotiations are ongoing, addressing a range of issues. In fact the adaptation financing landscape is so rapidly changing that any specific recommendations would likely be outdated before they went to print.

Whatever the final arrangements, however, there are certain principles that should guide their development. 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.

Water resources management investments should also be viewed as sustainable development financing that delivers adaptation benefits. Similarly multipurpose hydropower development (with flood and drought benefits) provides opportunities to deploy mitigation financing with adaptation benefits. These sorts of multiple bottom line investments are being explored and should be promoted in the adaptation finance architecture.

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.

Thus in some transboundary basins, the best climate change adaption interventions for any individual country might lie in basin-wide information and monitoring systems, or in upstream infrastructure investments and/or reoperations in a neighbouring riparian country for joint management of shared water resources. 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.

4 Conclusions

Just as energy use is the focus for mitigation efforts, water is arguably the primary medium through which climate change impacts will be felt and water management will inevitably become a focus for adaptation.

However, many countries have not yet achieved a reasonable level of water security. Efforts to achieve and sustain water security are thus not just an essential response to climate change, but also an immediately beneficial investment that will help to buffer economies, societies and ecosystems from today's climate variability.

A mix of both 'soft solutions', such as enhanced information, warning systems and stronger management institutions, and 'hard solutions,' such as infrastructure, will be needed to minimize the uncertainty and disruptions that climate change will bring through the hydrological cycle.

A coherent approach to promote this drive for water security, that will address both current climate variability as well as the challenges of climate change, is that of integrated water resources management. The foundation for this has already been laid by the decision at the Rio Summit in 1992 that an integrated approach to water resource management and development was essential to address emerging challenges.

Properly implemented, an IWRM approach is inherently adaptive as it should both inform water users about water challenges and provide a framework through which such challenges can be addressed. Since many countries are already promoting and implementing IWRM, this framework can and should also be used to address the challenges of climate change. This will obviate the need for new institutions and activities and should help to mainstream adaptation or 'climate-proofing' into national development plans.

There is, however, evidence that the resources currently made available for water resource management are inadequate for the task. Therefore, it is important to ensure that reliable core funding for this ongoing activity is provided even as specific adaptation funding initiatives are launched.

This will help to avoid disconnected adaptation initiatives related to the water environment. Advancing and sustaining water security is an important goal today, and a 'stretch' goal for tomorrow's climate change adaptation. 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.

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