Managing Water under Uncertainty and Risk

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THE UNITED NATIONS WORLD WATER DEVELOPMENT REPORT 4

VOLUME 1

UN WATER Report

United Nations Educational, Scientific and Cultural Organization

World Water Assessment Programme

UN WATER

UN WATER Reports

UN-Water is the United Nations inter-agency coordination mechanism for all freshwater related issues. Established in 2003, UN-Water fosters greater co-operation and information sharing among UN entities and relevant stakeholders.

UN-Water monitors and reports on the state, utilization and management of the world's freshwater resources and on the situation of sanitation through a series of inter-connected and complementary publications that, together, provide a comprehensive picture and, individually, provide a more in depth analysis of a specific issues or geographic areas.

PERIODIC REPORTS:

World Water Development Report (WWDR)

is coordinated by the World Water Assessment Programme (WWAP) on behalf of UN-Water and published every three years. It provides a global strategic outlook on the state of freshwater resources, trends in use of the resource base in the various sectors (inter alia, agriculture, industry, energy) and management options in different settings and situations (inter alia, in the context of urbanization, natural disasters, and impacts of global climate change). It also includes regional assessments.

- ✓ Strategic outlook
- ✓ State, uses and management of water resources
- ✓ Global
- ✓ Regional assessments
- ✓ Triennial (4th edition)

Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS)

is produced every two years by the World Health Organization (WHO) on behalf of UN-Water. It provides a global update on the policy frameworks, institutional arrangements, human resource base, and international and national finance streams in support of sanitation and drinking water. It is a substantive input into the activities of Sanitation and Water for All (SWA).

- ✓ Strategic outlook
- ✓ Water supply and sanitation
- ✓ Global
- ✓ Regional assessments
- ✓ Biennial (since 2008)

The progress report of the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP)

is produced every two years. The JMP Report is affiliated with UN-Water and presents the results of the global monitoring of progress towards MDG 7 target C: to halve, by 2015, the proportion of the population without sustainable access to safe drinking-water and basic sanitation. Monitoring draws on the findings of household surveys and censuses usually supported by national statistics bureaus in accordance with international criteria.

- ✓ Status and trends
- ✓ Water supply and sanitation
- ✓ Global
- ✓ Regional and national assessments
- ✓ Biennial (since 1990)

In the years 2012 – 2013 UN-Water also publishes:

2012 **UN-Water Report on Integrated Approaches in the Development, Management and Use of Water Resources** is produced by UN-Water for the Rio+20 Summit (UNCSD 2012). A similar status report was produced in 2008 for UNCSD. The report assesses the status and progress of the management of water resources in UN Member States and reports on the outcomes and impacts of improved water resources management.

2013 **UN-Water Country Briefs** pilot project. They provide a strategic outlook on the critical importance of investments in water for human and economic development at country level.

More information on UN-Water Reports at: www.unwater.org/documents.html

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VOLUME 1

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FOREWORD

by Ban Ki-moon

Secretary-General of the United Nations

—

Water links the local to the regional, and brings together global questions of food security, public health, urbanization and energy. Addressing how we use and manage water resources is central to setting the world on a more sustainable and equitable path.

Universal access to safe drinking water and water resources is an imperative that cuts across all internationally agreed development objectives, including the Millennium Development Goals. Improving access to water improves health and education outcomes. It increases agricultural productivity. It is a force for gender equality and women's empowerment.

Yet pressures on freshwater are rising – from the expanding needs of agriculture, food production and energy consumption to pollution and the weaknesses of water management. Climate change is a real and growing threat. Without good planning and adaptation, hundreds of millions of people are at risk of hunger, disease, energy shortages and poverty.

This fourth edition of the *World Water Development Report* is the product of synergy within the United Nations system, in particular the United Nations World Water Assessment Programme hosted by UNESCO. It shines a spotlight on water use, analyses the question of managing water under uncertainty, and addresses gender issues throughout. The result is a call to action – to strengthen mechanisms of global coordination, to improve national institutions and to weave the two levels more tightly together.

This report is also intended to contribute to the Rio+20 United Nations Conference on Sustainable Development. If Rio+20 is to succeed, it must renew political commitment to integrated approaches to the sustainable management of the world's freshwater resources. Just as water is central to every aspect of life on earth, it must lie at the heart of the new vision we forge for sustainable development for the century ahead.

Ki-Moon Ban

Ban Ki-moon

FOREWORD

by Irina Bokova

Director-General of UNESCO

—

What is the state of the world's freshwater today? What can we expect in the future? What must we do now to prepare better for tomorrow?

These questions concern the ability of women and men across the world to live in dignity. They touch upon the need to manage sustainably the earth's increasingly finite resources. They go to the heart of all efforts to reach internationally agreed development goals, including the Millennium Development Goals. Freshwater is a core issue for sustainable development – and it is slipping through the cracks.

We need new leadership on freshwater today. This leadership must bring together the multitude of actors involved in using and managing water. It must link different sectors and activities into a coherent whole. It must join the local with the national, and the regional to the global. We must manage freshwater more sustainably in order to make the most of it for the benefit of all. For this, we need a clear map of where we stand.

The fourth edition of the *World Water Development Report* provides this map. Hosted by UNESCO, the United Nations World Water Assessment Programme has brought together members and partners of UN-Water to draw a unique picture of the state, use and management of the world's freshwater resources. The report highlights different regions and examines the global pressures of uncertainty and risk. I am especially pleased that gender issues are mainstreamed throughout the analysis.

The conclusions are clear. Freshwater is a cross-cutting issue that is central to all development efforts. It faces rising challenges across the world – from urbanization and overconsumption, from underinvestment and lack of capacity, from poor management and waste, from the demands of agriculture, energy and food production. Freshwater is not being used sustainably according to needs and demands. Accurate information remains disparate, and management is fragmented. In this context, the future is increasingly uncertain, and risks are set to deepen.
If we fail today to make water an instrument of peace, it might become tomorrow a major source of conflict.

More than ever, we need Integrated Water Resources Management to provide coherent leadership. We need better information gathering and sharing on the state of freshwater, on the nature of demand and its use. We need better systems for measurement and control at the local, national and global levels. We must start early, by building water issues into education. We need also for governments, the private sector and civil society to work more closely together and to integrate water as an intrinsic part of their decision-making.

Our next step must be taken in Rio, by the United Nations Conference on Sustainable Development. Rio+20 must set a roadmap for the twenty-first century that includes a new direction for the sustainable use and management of the world's freshwater resources. Water is the condition for life; it is vital for sustainable development and for lasting peace. We must act today to protect it tomorrow. This means moving firmly in the direction charted by the *World Water Development Report*.

Irina Bokova

FOREWORD

by Michel Jarraud

UN-Water Chair and Secretary-General of WMO

—

It is an honour and a pleasure to have been invited to provide my brief remarks to the fourth edition of the United Nations *World Water Development Report*.

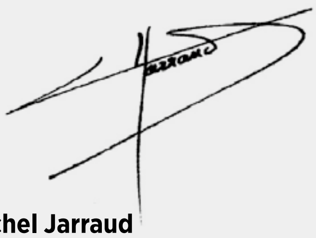
The report is the result of a broad collective teamwork of UN-Water agencies and partners, implemented through its World Water Assessment Programme, in particular to meet the challenges, risks and uncertainties blocking the road to sustainable development and the achievement of the UN Millennium Development Goals.

Today, water issues are positioned higher than ever on the international agenda, thanks in particular to the inspired leadership of the UN Secretary-General, who has expressed that *'Safe drinking water and basic sanitation are intrinsic to human survival, well-being and dignity'*.

The cross-cutting nature of water and the vital implications of international collaboration in this key area, spurred by the UN System acting *As One* through UN-Water, are intrinsic elements of the UN-Water mission statement and thereby essential for our actions to provide knowledge, tools and skills to various socio-economic sectors and to prop up high-level decision-making at global, regional and local scales.

This is especially significant at times of such crises as we encounter today when, for example, several consecutive seasons of drought in the Horn of Africa have left millions on the borderline of survival, thereby requiring emergency food assistance as well as sanitation, energy generation, and many other forms of support in disaster risk reduction.

I look forward to delivering the important messages of this key report in Rio in June 2012. However, since I have taken office very recently as UN-Water Chair, I wish to underscore that I make no claim of personal merit for this achievement which reflects the results of three years of collective UN-Water efforts.



Michel Jarraud

PREFACE

by Olcay Ünver

Coordinator, United Nations World Water Assessment Programme

—

Released every three years since March 2003, the United Nations *World Water Development Report* (WWDR), a flagship UN-Water report published by UNESCO, has become the voice of the United Nations system in terms of the state, use and management of the world's freshwater resources. The report is primarily targeted at national decision-makers and water resource managers, but is also aimed at educating and informing a broader audience, from governments to the private sector and civil society. It underlines the important roles water plays in all social, economic and environmental decisions, highlighting policy implications across various sectors, from local and municipal to regional and international levels.

Coordinated by the World Water Assessment Programme (WWAP), this fourth edition of the WWDR is the result of a concerted three-year effort by UN-Water agencies, in collaboration with dozens of scientists, professionals, NGOs and other UN-Water partners. The report addresses the most salient strategic and technical aspects relating to how and why we need to use, manage and allocate water to meet multiple, often competing goals, from all major policy directions – from poverty alleviation and human health to food and energy security and environmental stewardship. In describing how water underpins all aspects of development, the report provides a critical point of reference for linking water to global policy tracks, such as those for poverty eradication, including the Millennium Development Goals; sustainable development, the Rio+20 process; climate change, and the respective COP process.

While the report is factual, containing the most current information available concerning the state of knowledge about our water resources and covering the most recent developments that affect it, the report also provides decision-makers with concrete examples of approaches and potential responses for addressing water-related challenges from both a water management perspective and a broader political and sectoral scope, which covers development, financing, capacity-building and institutional reform.

The fourth edition of the WWDR builds upon the previous three editions. Similarly to the first two editions, it includes a comprehensive and up-to-date assessment of several key challenge areas, such as water for food, energy and human health, and governance challenges such as institutional reform, knowledge and capacity-building, and financing, each produced by individual UN agencies. And, as in the third edition, the report offers a holistic and integrated approach to examining the links between water and the drivers that create pressures on the resource, climate change, ecosystems and various aspects of human security as embodied under the Millennium Development Goals and other key global policy tracks. This fourth edition also continues to focus on how decisions made outside the 'water box' affect the resources and other users, linking water to a number of cross-cutting issues. Through this approach, the report illustrates how interactions between water and a multiplicity of externalities can be incorporated into analyses and decision-making processes in various sectors and domains. It is fortuitous that the release date for this report occurs a few months prior to the Rio+20 Earth Summit, thus providing a sound basis for discussions on the future of our planet in which the centrality of water can be clearly highlighted.

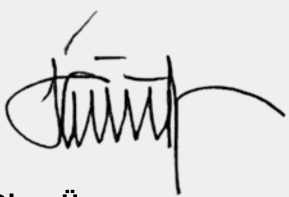
Several new elements have also been added to this fourth edition of the report. For the first time since the inception of the series, the WWDR4 has been developed under an overarching theme – 'Managing Water under Uncertainty and Risk' – which has served as a guide for the authors and collaborating agencies, allowing for the streamlining of the many different written contributions into a cohesive narrative. Second, the report has been enriched by the addition of five regional reports through the efforts of the five Regional UN Economic Commissions, which complement the challenge area reports by offering a more geographically focused examination of the issues and challenges related to water, including the identification of critical 'hotspots'. Third, this edition reports on the results of the first phase of the WWAP World Water Scenarios Project, which examines possible future developments in externalities that impinge upon water stress and sustainability. Finally, the entire report underwent a gender mainstreaming exercise to ensure that the important gender and social-equity issues were properly and systematically addressed, and a new chapter specifically focused on gender and water has been included in this edition.

In order to help countries improve their self-assessment capability by building on existing strengths and experiences, the report is once again accompanied by a set of case studies from countries around the world highlighting the state of water resources where different physical, climatic and socio-economic conditions prevail.

A series of collective and collaborative efforts has led to a highly comprehensive and integrated WWDR. Coordinating the fourteen challenge area reports, five regional reports and three special reports that make up the chapters in Volume 2, as well as the supplementary material and the multitude of comments from partners, reviewers and the general public over three years was a challenging process. The members of WWAP's Technical Advisory Committee were particularly generous in providing insight and expertise to the production team. Given such a broad scope of expertise over such a wide range of interests and sectors for which water is a vital component, a focused analysis was required to achieve a balanced structure to the report and to provide the most up-to-date knowledge and information in a consistent and harmonious manner.

It is hoped that this report, like its previous editions, will continue to be the main reference document about water and the central role it plays in all aspects of human development, that it will continue to be considered as essential reading for decision-makers, their advisors and anyone interested in – and concerned about – the state and the use of our planet's freshwater resources, and that this edition will reach an ever-widening audience that includes actors outside the 'water box' who make or influence broad socio-economic policies that affect water.

On behalf of the staff of WWAP and the authors, writers, editors and contributors of the fourth edition of the WWDR, I extend my sincerest appreciation to the members of UN-Water and its partners in producing this authoritative and critically important report that will serve as the knowledge base for understanding and solving water-related challenges around the world. A special word of thanks goes to Irina Bokova, Director-General of UNESCO, without whose crucial support this report would not be completed. Last but not the least, my undying gratitude goes to all members of the WWAP Secretariat, whose names are listed in Acknowledgements, for their professionalism and ceaseless efforts in completing the report.



Olcay Ünver

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2nd Meeting of the Interim Core Group for the production of the WWDR4, 21–29 May 2009, Perugia, Italy.
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Workshop for the production of the WWDR4, 14 August 2009, Stockholm, Sweden. Participants: UN-Water Members and Partners, WWAP Secretariat.

Issues Workshop for the production of the WWDR4, 16–17 November 2009, Perugia, Italy. Participants: Yoganath Adik, Guy Alearts, Kodwo Andah, Kusum Athukorala, Reid Basher, Anders Berntell, Peter Koefoed Bjørnsen, Giorgio Cesari, Emmanuel Chinyamakobvu, Thomas Chiramba, Rudolph Cleveringa, Richard Connor, William J. Cosgrove, Andre Dzikus, Karen Frenken, Gilberto Gallopin, Joakim Harlin, Pierre Hubert, Angelo Izzo, Nancy Kgengwenyane, Spyros Kleitsas, Peter Kristensen, Henrik Larsen, Lifeng Li, Josefina Maestu, Anil Mishra, Jack Moss, Mike Muller, Johnson Oguntola, Walter Rast, David Tickner, Håkan Tropp, Lucio Ubertini, Konrad Vielhauer, Enrique Urrutia López de Viñaspre and James Winpenny.

Coordination Meeting on Substance, 16–17 March 2010, Perugia, Italy. Participants: Reid Basher, Peter Koefoed Bjørnsen, Claudio Caponi, Emmanuel Chinyamakobvu, Rudolph Cleveringa, Richard Connor, William J. Cosgrove, Rainer Enderlein, Karen Frenken, Matt Hare, Melvyn Kay, Eric Mimo, Anil Mishra, Diego Rodriguez, Kulwant Singh, Håkan Tropp and Pieter Van Der Zaag.

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Consultations

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- Short survey on lessons learnt from the WWDR3 process, January–March 2009
- Consultation meetings at the 5th World Water Forum, March 2009
- WWDR3 Side Event at the 5th World Water Forum, March 2009
- WWDR3 Production Team meeting, March 2009
- Meeting of the WWAP Technical Advisory Committee, March 2009
- 1st UN-Water and stakeholders electronic surveys, June 2009
- UN-Water Delphi, July 2009
- Side Event at the Stockholm World Water Week, August 2009
- Public consultation on the table of contents, January 2010
- Expert survey on drivers, April 2010
- Side Event at the Stockholm World Water Week, August 2010
- Side Event at the 3rd Africa Water Week, November 2010
- Public consultation on Draft 1 of Parts 1 and 2, December 2010
- Policy survey for decision-makers, January 2011
- Side Event at the Stockholm World Water Week, August 2011

We apologize for any inadvertent errors or omissions of contributors to the report.

MAIN MESSAGES

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Compiled by William J. Cosgrove

Chapter 1. Recognizing the centrality of water and its global dimensions

Water is a critical natural resource upon which all social and economic activities and ecosystem functions depend. Managing water well requires appropriate governance arrangements that move considerations of water from the margins of government to the centre of society. On national and local scales, appropriately funded infrastructure and adequately funded robust governance mechanisms are required to protect water resources and ensure sustainable development and the equitable distribution of water-derived benefits.

The cross-cutting nature of the resource and its global dimensions underline the importance of addressing water issues in the context of all existing and developing international processes.

There are major uncertainties about the amount of water required to meet demand for food, energy and other human uses, and to sustain ecosystems. These uncertainties are compounded by the impact of climate change on available water resources.

Greater recognition is needed of the fact that water is not solely a local, national or regional issue that can be governed at any of those levels alone. On the contrary, global interdependencies are woven through water, and decisions relating to water use on a local, national, river basin or regional level often cannot be isolated from global drivers, trends and uncertainties.

Water demands and uses are often managed in silos with each focused on meeting specific developmental objectives, rather than as part of an overarching and strategic framework that balances different water uses in order to optimize and share its various benefits across society and the economy. This fragmentation increases risks to the sustainability of water resources as well as to the different development objectives that depend upon (and may be in competition for) limited supplies. Climate change exacerbates this problem still further.

The job of delivering adequate water for social, economic and environmental needs is often understood as the preserve of the 'water sector', which is expected to provide the appropriate infrastructure and channel water in the right direction. Yet in reality, water cuts across all social, economic and environmental activities. As such, it cannot be confined to one sector; its governance requires cooperation and coordination across diverse stakeholders and sectoral 'jurisdictions'. Furthermore, water availability must be understood within the context of the hydrological cycle, which is influenced by multiple factors, trends and uncertainties that extend beyond a narrow sectoral focus.

Climate change is a central external driver that affects both water and demands for all uses directly; mitigation measures are concentrated around the reduction of energy consumption and carbon emissions, while adaptation means planning and preparing for increasing hydrological variability and extreme weather events, including floods, droughts, and storms.

Addressing water challenges necessitates interventions across an entire economy, undertaken by strong institutions with the authority and leadership to take a proactive rather than a reactive role in water management, and to drive the productive use of water across sectors within the framework of environmental sustainability. Members of the water community have the duty to inform and provide guidance on decision-making and to regulatory authorities on how to use and managed the resource sustainably, so as to optimize and share its many benefits.

Efficiency and productivity gains alone cannot alter global patterns of unequal supply of resources and consumption or access to benefits. Addressing the

© Peter Prokosch/UNEP/GRID-Arendal (http://www.grida.no/photolib) cross-sectoral and global dimensions of water will require that all countries take an interest and make specific commitments in the global forums designed to address and create solutions to impending resource challenges. The water community in general, and water managers in particular, have the responsibility of informing the process.

Implementing the outcomes from global policy agreements will remain a national imperative, and countries are responsible for setting international policy in the first place. Setting the framework requires a widening of the sectoral and spatial horizons of all those who have a stake in water management. However, many of the global policy agreements have been developed without proper local and national consultation processes and are, in many cases, general agreements that do not reflect the political economy and institutional capacities of the countries, thus compromising the overall effectiveness of said policies at national and subnational levels.

Part 1: Status, trends and challenges

Chapter 2. Water demand: What drives consumption?

Agriculture accounts for 70% of all water withdrawn by the agricultural, municipal and industrial (including energy) sectors. Responsible agricultural water management will make a major contribution to future global water security.

Predicting future water demand for agriculture is fraught with uncertainty. Future demand for water in this sector is in part influenced by demand for food, which depends in part on the number of people needing to be fed, and in part on what and how much they eat. This is complicated by, amongst other factors, uncertainties in seasonal climatic variations, efficiency of agriculture production processes, and crop types and yields.

The main challenge facing the agricultural sector is not as much growing 70% more food in 40 years, but making 70% more food available on the plate. Reducing losses in storage and along the value chain may go a long way towards offsetting the need for more production.

Innovative technologies will be needed to improve crop yields and drought tolerance; produce smarter ways of using fertilizer and water, new pesticides and non-chemical approaches to crop protection; reduce postharvest losses; and ensure more sustainable livestock and marine production. The industrialized countries are well placed to take advantage of these technologies, but they must also take responsibility to ensure that the least developed countries have opportunities to access them on equitable and non-discriminatory terms.

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Reducing vulnerability to drought will require investment in both constructed and 'green' infrastructure to improve water measurement and control and, where appropriate, increase surface water and groundwater storage in constructed reservoirs and in natural storage in wetlands and in the soil.

Most benefits are expected to come from applying existing water management technologies and adapting them to new situations.

Over 1 billion people lack access to electricity and other clean sources of energy today. When added to meeting these needs, external challenges, including demographic development from population increase and migration and increased economic activity, will create a surge of energy consumption, particularly in non-OECD countries.

Energy and water are intricately connected. There are different sources of energy and electricity, but all require water for various production processes, including extraction of raw materials, cooling in thermal processes, cleaning materials, cultivation of crops for biofuels and powering turbines. Conversely, energy is required to make water resources available for human use and consumption through pumping, transportation, treatment, desalination and irrigation.

Regions that are water scarce will face more water-for-energy stresses than others and will need to explore more water-efficient technologies to develop both primary energy and electric power.

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Water and energy policies, which are often made in different government departments or ministries, will need to be integrated, with policy-makers increasingly working in close coordination.

Effective operation of an industry requires a sustainable supply of water in the right quantity, of the right quality, at the right place, at the right time and at the right price.

Industry should play an important role in effectively addressing the unsustainable exploitation of freshwater resources around the world by addressing first its own priorities and values.

The urban population of the world is forecast to grow to 6.3 billion people in 2050, from 3.4 billion in 2009. Urban growth will be equal to all of the world population growth over this period plus some net moves from the current rural population. Problems of adequate water supply, sanitation and drainage will increase in the urban slum areas already faced with a backlog of unserved populations. Initiatives worldwide are emerging to address the need for improved and comprehensive urban water planning, technologies, investment and associated operations.

Water management in urban areas can benefit from more comprehensive urban planning and integrated urban water management (IUWM). IUWM involves managing freshwater, wastewater and stormwater as links within the resource management structure, using an urban area as the unit of management.

Ecosystems underpin the availability of water, including its extremes of drought and flood, and its quality.

Growing attention to resolving the increasing competition for water between ecosystems and socio-economic sectors signals progress towards better integrated water management and more sustainable development.

Chapter 3. The water resource: Variability, vulnerability and uncertainty

Freshwater supplies are erratically distributed in time and space. From one year to the next, there can be considerable variability between arid and humid climates and wet and dry seasons. Water resource management plans and policies need to take into account this variability and distribution of freshwater supplies.

The state of water resources is influenced by withdrawals to meet socio-economic demands. This in turn is affected by drivers such as population growth, economic development and dietary changes, as well as the need for control of water resources to protect settlements in flood plains and drought prone regions.

The global groundwater abstraction rate has at least tripled over the past 50 years. This has fundamentally changed the role of groundwater in human society, in particular in the irrigation sector, where it has triggered an 'agricultural groundwater revolution'.

Groundwater is crucial for the livelihoods and food security of 1.2 to 1.5 billion rural households in the poorer regions of Africa and Asia, and for domestic supplies of a large part of the population elsewhere in the world.

Withdrawals in many basins are exceeding the rate of recharge and are unsustainable.

In spite of valid concerns about unsustainable abstraction rates and pollution in many parts of the world, groundwater resources if carefully managed can make a significant contribution to meeting the demand for water in the future and to adapting to climate change. The shrinking of glaciers is, in the short term, adding water to streamflows over and above annual precipitation and thus increasing water supply; in the longer term (decades to centuries) as glaciers disappear those additional sources of water will diminish and the buffering effects of glaciers on streamflow regimes will lessen.

Sufficient water supply, of good quality, is a key ingredient in the health and well-being of humans and ecosystems and for socio-economic development. Though there have been some regional successes in improving water quality, there is no data to suggest that there has been an overall improvement in water quality on a global scale.

Water quality is just as important as water quantity for satisfying basic human and environmental needs, yet it has received far less investment, scientific support, and public attention in recent decades than water quantity.

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Poor water quality has many economic costs associated with it, including degradation of ecosystem services; health-related costs; impacts on economic activities such as agriculture, industrial production and tourism; increased water treatment costs; and reduced property values.

With freshwater projected to become an increasingly scarce resource in the coming years, the costs associated with addressing water quality problems can be expected to increase.

Chapter 4. Beyond demand: Water's social and environmental benefits

Improving water resource management, increasing access to safe drinking water and basic sanitation and promoting hygiene have the potential to improve the quality of life of billions of individuals and are critical for the achievement of the goals to reduce child mortality, improve maternal health and reduce the burden of waterborne disease.

A preventive and collaborative approach of Water Safety Planning has demonstrated benefits, including cost savings and sustainable improvements in water quality. Each risk management solution needs to be tailor-made to the water supply in question, and demands that key stakeholders become engaged and committed to a common goal. These include land users or householders who may discharge industrial, agricultural or domestic waste into a catchment area, policymakers from various ministries overseeing the implementation and enforcement of environmental regulations, practitioners delivering water and consumers at the tap.

Poor women shoulder the brunt of economic crises and women with less education tend to increase their work participation more in times of crisis in almost every region of the world.

Social and financial investment along with policy support to improve women's access and control over water resources will reduce vulnerability to poverty and enable women to secure sources of food and livelihoods, and to maintain the health of themselves and their families.

Ecosystems deliver multiple benefits (services) that are essential for sustainable development. Many of these key services are derived directly from water, and all are underpinned by it. Trends in ecosystem health, therefore, indicate trends in the delivery of these overall benefits and provide a key indicator of whether we are in or out of balance with water.

Trends in ecosystems, including the life they support, are telling us that things are out of balance. Policymakers and managers need to recognize that ecosystems do not consume water – they supply and recycle it – and water taken from ecosystems unsustainably reduces their ability to deliver the benefits we need ecosystems to provide.

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While we are getting better at saving lives, saving livelihoods and assets remains a key development challenge: water-related disasters are a major obstacle to poverty reduction efforts and to meeting development objectives, such as the Millennium Development Goals.

One of the major impacts of desertification, land degradation and drought (DLDD) associated water scarcity is felt through food insecurity and starvation among affected communities, particularly in developing countries in the drylands.

If dryland countries could reduce the impacts of DLDD on water resources and achieve water security, opportunities of achieving food security would be greatly enhanced.

Different developmental sectors are often in competition with each other for the finite water resources upon which they all depend. While they can be 'in competition' over water, it is clear that *all* the benefits of water are required for sustainable economic development. In countries and regions where water resources are limited, decisions made to generate benefits through water from one sector often produce negative consequences for other sectors. Uncertainties regarding future demands add to the complexity of the challenge.

Where water resources are limited, certain trade-offs may be required in order to allocate water towards different uses in order to maximize the various benefits water provides though different developmental sectors. This is a critical yet difficult and complex challenge. Decisions about water allocation are not merely social or ethical, but are also economic, such that investing in water infrastructure and management generates increasing returns though these various benefits.

Chapter 5. Water management, institutions and capacity development

Water is characterized by the fact that all benefit from it but few understand why and fewer actually manage it.

Water management requires a mix of structural and non-structural options. Adaptive Integrated Water Resources Management (IWRM) can provide the necessary integration of water management across sectors, policies and institutions in a continuous process of adjustment that attempts to deal with the increasingly rapid changes in our societies, economies, climate and technologies.

Competing user groups (e.g. water utilities, farmers, industry and mining, communities, environmentalists) can influence strategies for water resource development and management, meaning that the process becomes more political and less purely technical as integration occurs and a potential basket of benefits emerges.

Water management now has to account for unforeseeable changes in the nature and timing of issues like population growth, migration, and globalization, changing consumption patterns, technological advances, and agricultural and industrial developments. The spectre of climate change has drawn attention to the importance of these and added a new dimension. The rules of the game for water are often dictated by actors other than water managers, and are not set with water as their central focus or with the recognition of its pivotal importance. Making coherent decisions, with the various trade-offs they imply, calls for some institutional machinery linking decision-makers in key sectors with those responsible for water management. A wider group of stakeholders needs to be involved in the 'rule-setting' process.

Water institutions are still largely technology and water supply driven. To improve the effectiveness of these institutions, the emphasis has to gradually change from technological solutions to management of processes and people, involving inclusive decision-making and bottom-up approaches.

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At the national level, it is essential to establish sustainable frameworks for capturing, storing and disseminating data, information and knowledge to all stakeholders in the water sector, thus contributing to improved decision-making regarding water resource management.

At the community level, concrete steps towards sharing information and knowledge, contributing to improved decision-making and resource management can include creating dialogue platforms involving local stakeholders and their assisting service organisations; for example, government institutions, extension services, NGOs and other service providers.

Chapter 6. From raw data to informed decisions
Information about water supply and use is becoming increasingly important to national governments, who need reliable and objective information about the state of water resources, their use and management.

Farmers, urban planners, drinking water and wastewater utilities, the disaster management community, business and industry, and environmentalists all need to be informed.

The data required to populate the indicators are seldom systematically or reliably available at a global, national, regional or basin level. If actual data are not obtained, trends will not be tracked, even if they are substantial.

For the purposes of planning and design, engineers have typically assumed that the hydrological processes in a particular watershed or basin could be described by probability distributions that were not changing over time; that is, the historical statistical characteristics of those processes were assumed essentially constant over time, or stationary. The more these extreme events happen due to changes in the Earth's climate or from unpredictable human behaviour, the more challenging it is to plan and manage water. The question is how best to include these nonstationarity considerations of both water supply and demand in water planning and management.

Concerns about climate change, one of the factors that have led to the growing interest in water indicators, explicit recognition that the 'stationary hydrology' assumption can no longer be used as the basis for assessment of water availability. This has focused attention on the limited availability of global data on stream flows, on which estimates of water resource availability must be based. While there are a great deal of available data on precipitation, which can be measured by remote sensing, changes in runoff to rivers or recharge of groundwater are much harder to measure.

Because of the relatively low value and wide distribution of water, its use is often not measured directly. Because water resources are often 'shared' between a number of different political jurisdictions, there is often a disincentive for upstream communities to share information about resource availability and use with downstream jurisdictions, as the information may be used in disputes about the division of the resource.

To achieve a balanced allocation and protection of water resources, indicators should support policy instruments which are carefully chosen and designed. They may include regulation (e.g. technical standards, performance standards), quotas, access rules and allocation procedures, as well as economic instruments (especially pricing mechanisms and payments for ecosystem services).

Because water occurs in natural structures whose behaviour often varies from one season to the next,

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measuring simple parameters such as flow is often extremely expensive. There is a huge resource base from remote sensing, which has not yet been translated into significant flow of useful processed information about water and its use. However, using remote sensing data without ground truth may be risky; strengthening existing hydromet networks and services is a necessary condition for proper water resources management, planning, design and operation.

The most effective driver of efforts to improve the flow of information about water will be a demand from policy-makers and decision-makers in the socio-economic sectors of activity.

From a government perspective, economic policy-makers have recognized that water resources have an important but largely unaccounted for influence on national economies. There are now significant opportunities for the global community of water practitioners, as well as water users and the much broader community that has a stake in water, to make substantial improvements in the availability and quality of information about the resource, its use, users, benefits derived from its use and how these benefits are allocated, and who bears the costs and negative impacts.

Chapter 7. Regional challenges, global impacts

Africa

Sub-Saharan Africa faces endemic poverty, food insecurity, very low coverage of both drinking water and sanitation, and pervasive underdevelopment, with almost all countries lacking the human, economic and institutional capacities to effectively develop and manage their water resources sustainably.

Overall, only one in four people in Africa has electricity. Hydropower supplies 32% of Africa's energy; only 3% of its renewable water resources are exploited for hydroelectricity. Yet the region has vast hydropower potential – enough to meet all the continent's electricity needs.

Drought in sub-Saharan Africa is the dominant climate risk; it destroys economic livelihoods and farmers' food sources and has a significant negative effect on GDP growth in one-third of the countries. Floods are also highly destructive – to infrastructure and transportation and to goods and service flows, and they can contaminate water supplies and cause waterborne disease epidemics.

Europe and North America

The relatively affluent lifestyles of most Europeans and North Americans make large demands on the region's water resources. North Americans, the highest per capita water users in the world, however, consume two and a half times the volume that Europeans use per capita: one reason is that water is relatively inexpensive compared to other industrialised countries.

Some 120 million people in the European region do not have access to safe drinking water. Even more lack access to sanitation, resulting in water-related diseases. Water quality remains a persistent problem in many parts of the region. Agrochemicals in particular have had a detrimental impact on water resources throughout the region as nitrogen, phosphorus and pesticides run into water courses.

The Water Framework Directive concluded in 2000, and including more recent directives on standards and groundwater, is the most important piece of EU water legislation and the only such supra-national water arrangement in the world. It has accelerated and deepened a historical process of transboundary water management.

Asia-Pacific

The Asia and Pacific region is extremely dynamic, undergoing rapid urbanisation, economic growth, industrialization, and extensive agricultural development. Although these trends are desirable in many ways, they also represent drivers that are affecting the region's capacity to meet its socioeconomic water development needs. They are accompanied by the intensive use of resources that exert considerable pressure on aquatic ecosystems, which continue to deteriorate.

Food security is an important issue since about two-thirds of the world's hungry people live in Asia.

The Asia-Pacific is the world's most vulnerable region with respect to natural disasters, which undermine economic development to varying degrees. Much economic growth is generated in coastal and flood-prone areas, for example, which are heavily populated and especially vulnerable to typhoons and rainstorms.

The Pacific's small island developing states (SIDS) are particularly vulnerable to environmental natural hazards, such as tropical cyclones, typhoons and earthquakes turning into disasters. Climate change will further exacerbate the vulnerability of SIDS with anticipated sea-level rise and the risk of storm surge and beach erosion. One tropical cyclone can negate years of development efforts.

The region is shifting from predominantly short-term benefit planning and development of water infrastructure, to a more strategic and long-term benefit planning concept that also addresses ecological efficiency in economic development.

Latin America and the Caribbean

Latin America and the Caribbean (LAC) is basically a humid region although it contains some very arid areas. The pattern of water use in the region can be described as spatially sporadic and highly concentrated in relatively few areas.

With the exceptions of Mexico, Brazil and some of the small Central American countries, LAC economies depend on the export of natural resources. Global demand for these products, which include minerals, food and other agricultural products, timber, fish and tourism services, has increased notably in recent years. This has implications for competing water demands and the export of 'virtual' water from the region.

Although most LAC countries enjoy high levels of coverage of improved water and sanitation, there is a large variation in the quality of services and important differences between rural and urban areas and among countries. Almost 40 million people still lack access to improved water and nearly 120 million to proper sanitation facilities. The majority of those without access to services are poor and live in rural areas.

In general, poor governance in many LAC countries extends from the top to the bottom. It is not restricted to the management of the water resource, but rife in the management of most water-based services. With relatively weak water management capacities, the region's poorest countries in Central America, the Caribbean and the Andes will be at the highest risk from the impacts of climate change.

Arab and Western Asia region

Population growth and migration, growing consumption, regional conflicts and governance constraints in the Arab and Western Asia region have resulted in increasing risks associated with water quantity and quality, but are accompanied by the sustainable management of shared resources and their use, as well as the success of policies to promote rural development and food security.

Water scarcity leads to food insecurity concerns in the Arab region. Imported grain accounts for a large amount of 'virtual' water consumed in the Middle East and North Africa, which was importing 50 million tonnes of grain annually by the year 2000. This has fostered interest in agricultural investments outside the region to produce food, which in effect increases the importation of virtual water.

Cyclical conflict has been characteristic of the Arab region. Violent conflict has also destroyed water infrastructure at different times in Beirut, Kuwait and Lebanon, requiring rehabilitation instead of expansion of delivery. About 66% of the Arab region's available surface water originates from outside of the region. At times, this has led to conflict with upstream countries. Local-level water conflicts can also exist between administrative districts, communities and tribes.

Regional–global links: Impacts and challenges

Water-related natural disasters pose major impediments to achieving human security and sustainable socio-economic development. Droughts have significantly impacted agricultural production, which in turn have contributed to soaring food prices and shortages. These increases have other major socio-political impacts and can lead to far reaching consequences such as food riots and political instability.

Water shortages can cause conflicts of varying intensity and scale. Although conflicts may appear localized, they present challenges to the broader context of peace and security. Conflicts over water resources can also turn into or fuel ethnic conflicts – as ethnic conflict is most commonly fuelled by collective fears for the future, one can see how water scarcity could play into such fears.

There are useful reasons for incorporating the positive aspects of the market when considering water resources. For instance, one of the reasons for water resource depletion is that typically it has been undervalued as a resource. It is thus important to place a value on it. Whether earmarking it as a commodity is the best solution for placing value on it is subject to debate.

Whether through norms or values, water resources must be valued for their worth, else the trend of degradation will ensue.

Part 2: Managing water under uncertainty and risk

Introduction to Part 2

Political and social systems are changing in ways and with impacts not always predictable. Technology is evolving, living standards, consumption patterns and life expectancies are changing, and human populations are growing and increasingly moving to expanding urban areas. Consequently, land use and cover is changing, as is the climate. The rates at which these changes are occurring are often increasing and their long-term impacts are usually uncertain. Discontinuities are possible and tipping points can exist beyond which change is irreversible.

Adapting to change presents an opportunity. What has happened in the past cannot be changed, but the future can be influenced by the decisions being made now.

Water is a primary medium through which changes in human activity and the climate impact with the earth's surface, its ecosystems, and its people. It is through water and its quality that people will feel the impact of change most strongly.

Without proper adaptation or planning for change, hundreds of millions of people will be at greater risk

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of hunger, disease, energy shortages and poverty due to water scarcity, pollution or flooding. Adapting to changes in water quantity and quality, together with their risks and uncertainties, is a challenging area for water management.

The risks, or consequences of making decisions under uncertainty, can be qualified and even sometimes quantified. Robust decision-making is a tool that attempts to support different management actions under deep uncertainty.

Providing decision-makers with tools that show the broader water resource consequences of various decisions (actions, inaction) can substantially contribute to better overall resource management, and reduced threats and adverse impacts.

Chapter 8. Working under uncertainty and managing risk
Risk and uncertainty characterize much of what water managers and socio-economic policy-makers must deal with. The more they understand these uncertainties and risks, the more effectively they can plan, design and manage water systems to reduce these risks and uncertainties.

Today water planners and engineers are particularly concerned with uncertainties associated with extremes that have not yet been observed and are outside the envelope of variability defined by past events. The world is witnessing the occurrence of such extreme events today. Because of this water resources planners and managers must apply a significant amount of judgment in their analyses due to changes in land use, urbanization, and the impacts of a changing climate that influence future precipitation, evaporation, groundwater infiltration, surface runoff and channel flow.

No matter what design is chosen there is always a risk of failure. Questions that plague anyone making long-term decisions include what levels of risk are acceptable, and just how much more money, if any, should be spent on designs that reduce the costs of infrastructure expansion in the future, should future conditions warrant it.

When sufficient information is available to determine probabilities of decision outcomes and evaluate the consequences, decision-making can be based on risk analysis. Decision-making may be assisted by the use of a wide variety of analytical tools and techniques, varying from the simple to the sophisticated.

The decision process should encourage active participation from interested stakeholder groups. This will ensure that differences in the perception of risks and values are fully explored within the risk assessment and decision appraisal process. Interactive decision support models have been developed and successfully used to facilitate stakeholder participation.

In situations where it is difficult to assign probabilities to possible events or future outcomes, perhaps due to our limited understanding of human and ecological processes or due to the intrinsic indeterminism of complex dynamic systems, we can still create scenarios that force us to consider the possibility of such outcomes and whether or not we should make decisions that might lead to such outcomes. Water futures depend on human choices that are yet to be made.

Water management agencies with users and policy-makers need to participate in the development of alternate methodologies that take into account non-stationarity and make water resource projects more adaptable, sustainable and robust.

If humans are to live within the limits of their water resources (and there is no other choice), they must live within the limits of the natural systems that provide, treat and distribute those resources. Humans need to include natural ecosystems, along with built infrastructure and human activities that determine the allocation and use of water, in an integrated way, each affecting and benefiting the other and necessarily managed together within an integrated system of a river basin. Recognizing and managing the *interconnectedness* among living systems is a means of reducing both short and long-term risks.

Chapter 9. Understanding uncertainty and risks associated with key drivers

Projected pressures on water resources lie outside the control of water managers. These can significantly affect the balance between water demand and supply – sometimes in uncertain ways – and thus create new risks for water managers and users. Such increasing uncertainties and risks necessitate a different approach to water management strategies.

Drivers that directly impinge upon water stress and sustainability are the ecosystem, agriculture, infrastructure, technology and demographics. The ultimate drivers – governance, politics, ethics and society (values and equity) and climate change – exert their effect mostly through their impacts upon the proximate drivers.

In the absence of technological improvements or policy interventions, economic polarities will increase between water-rich and water-poor countries, as well as between sectors or regions within countries. This would mean higher numbers of people with higher needs competing for less water, of lesser quality. Because allocation will inevitably go to the highest paying sector or region, this may result in an increasingly significant portion of people not being able to satisfy their basic needs for food, energy, water and sanitation. This would not be mere stagnation, but would likely take the form of a distinctly regressive trend compared to current conditions.

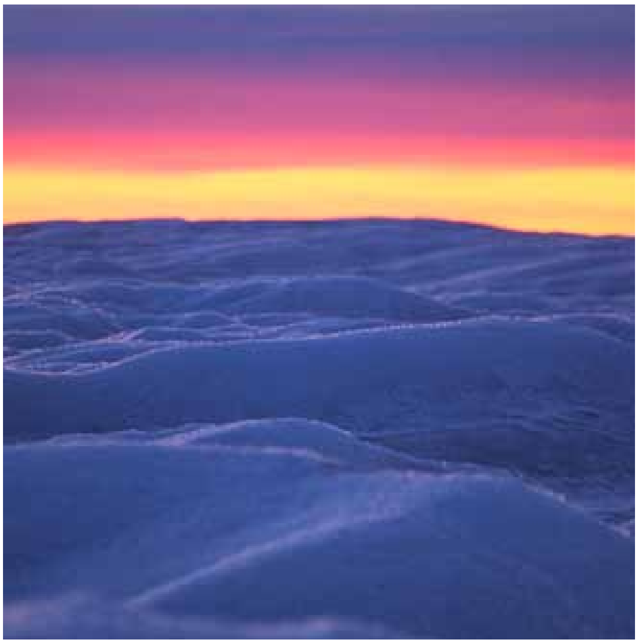
Further technology developments applicable to urban water production and waste handling that are likely to increase due to sheer urban population growth are also expected to contribute to reducing absolute water withdrawals and waste. Rapid uptake of these technologies would be paired with the anticipated evolution of global consciousness regarding human impacts on environment, and in particular, an increased understanding of water scarcity.

A legally binding international agreement to combat climate change could be in place by 2040, along with significant financing for awareness-raising and adaptation in low-income countries. Because most climate change impacts are felt through water, this would have positive repercussions on the overall levels of financing for water. This could mean higher levels of investment in water infrastructure, leading to reductions in waste and increases in sustainable mobilization, as well as increased sanitation network coverage.

Central water authorities, supported by river-basin institutions and decentralized entities would be given increased power and resources to effectively manage water within countries. This would promote dynamic and climate-responsive re-allocation of water among users, facilitated by well-regulated pricing and, potentially, innovative water rights trading mechanisms.
The development of water scenarios appears ever more necessary in the face of the risks and uncertainties involved in continuing with the business-as-usual modes of water management.

Chapter 10. Unvalued water leads to an uncertain future

Policies with profound effects on water are made by agents – politicians and officials in planning, economic, finance and water-using departments – that are heavily influenced by national economic and financial considerations. In addition, the case for investment in water, and for making the reforms to its development and management is also commonly framed in social, ethical, equity or public health terms.



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Water is increasingly becoming a critical factor in decisions for the location of economic activities such as industry, mining, power and tourism. Companies working or contemplating investment in water-stressed regions are becoming aware of their 'water footprint' and its impact on local communities, which could pose operational and reputational risk to their business.
Valuing the multiple socio-economic benefits of water is essential for improving decisions of governments, international organizations, the donor community, civil society and other stakeholders. Conversely, a failure to fully value all the benefits of water in its different uses is a root cause of the political neglect of water and its mismanagement.

The allocation of scarce water to competing uses lies at the heart of water management. In many parts in the world, increasing pressures on water resources are leading to a shortage of water to satisfy all needs. Stresses on water are mainly driven by four interrelated processes: population growth; economic growth; increased demand for food, feed and energy (of which biofuel is one source); and increased climate variability. Choices must be made about how to share, allocate and reallocate the increasingly scarce water within sectors, from one user group to another, or between sectors.

Chapter 11. Transforming water management institutions to deal with change

There are calls for a change in thinking away from separate ecosystems and social systems to socio-ecological systems instead. Rather than planning for one defined future, water management agencies increasingly need to improve their methods of assessment in order to respond to a range of possible future scenarios, all uncertain but presenting at varying degrees of probability.

Defining social risk tolerance and service reliability is part of a social contract to be determined through a continuing dialogue within each society, whether it be for new drugs, nuclear power plants or water infrastructure. IWRM is contextually shaped through this process to encompass the different dimensions of sustainability (ecological, biophysical, economic, social and institutional), but it is also often path dependent. Thus, effective IWRM is knowledge-intensive and simply needs to be adaptive if it is to continue to respond to exogenous changes over which it generally has little direct control. Adaptive management is a process that

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promotes flexible decision-making in the face of uncertainties as outcomes from management actions and other events become better understood.

In an inherently complex world, most of the important decisions impacting on water occur out of the water box. They are taken by leaders in governments, private sector and civil society. It is therefore important that new methods be developed for technical people to inform decision-makers in government, as well as those who are affected by these decisions. This requires a formal structuring of relationships between technical specialists, government decision-makers and society as a whole.

Looking beyond what is traditionally considered water management – going outside the water box – is inevitable. Interconnecting water management with land management and sectors like agriculture, mining and energy, at the institutional level, will enhance the probability of effective decision-making. Realising this is highly demanding on leadership. Overcoming the inertia of traditional approaches and resistance from various actors remains daunting. Decision-makers need support in putting these ideas into practice, as well as the courage to withstand criticism and to share power with other actors.

In order to make appropriate decisions to manage particular uncertainties and risks, they have to be clearly understood. It is therefore important to supply enough accurate information to provide the decision-maker(s) a certain amount of control when faced with uncertainty. Managing uncertainty can then become less stressful and result in more positive and realistic outcomes.

Chapter 12. Investment and financing in water for a more sustainable future

Water in all its facets needs financing – at a higher level than is currently happening – for both 'hard' infrastructure and the 'soft' but equally important items such as data collection, analysis and dissemination, human resources and technical capacities, regulation and other governance issues.

Investment in water infrastructure, in both its physical and natural assets, can be a driver of growth and the key to poverty reduction.

Adequately funded water governance is essential for reducing uncertainty and managing risks. Effective governance in areas such as environmental controls, groundwater monitoring and abstraction licensing, and monitoring and control of pollution can reduce the risk of overexploitation of water resources or of catastrophic surface water pollution and irreversible contamination of aquifers. Some of these governance functions can sometimes be self-financing through abstraction and pollution charges.

The neglect and decline of national observation systems cause loss of vital hydrological data. Investment in the technology needed to upgrade countries' water and water-related information bases can show good returns, and is being targeted for support by the international development community. Such information is of vital national concern, but is often a local, river basin, regional or international public good that is seriously underfunded and under-provided.

Adaptation and mitigation projects implemented by public agencies can draw on a range of development funds, including new adaptation funds created for this specific purpose. However, much of the adaptation/mitigation effort will fall to private companies, farmers and households, as well as subsovereign agencies that will have to rely on other sources of financing according to their particular situation.

Increasing the use of technologies, such as desalination and reclaimed water can reduce and distribute risk, compared with relying on withdrawals of fresh surface and groundwater. Desalination plants and some projects for the use of reclaimed water (entailing sizeable investment in wastewater treatment plants) potentially lend themselves to stand-alone commercial ventures funded from equity and commercial finance.

Raising commercial finance for water has become more difficult due to the global financial situation since 2007. This, as well as the problems typical of certain regions, most notably Latin America,, have discouraged new private interest in water infrastructure projects, and has unsettled partners in existing private public partnership (PPP) ventures. The financial climate has affected both the supply of risk capital (e.g. equity) and loan capital to finance these concession deals, as liquidity has become scarce, and the problems of international banks have had repercussions on local banks. Many innovative deals, developed with technical assistance and risk-sharing from donor agencies, are at risk.

As a general principle, the risk of financial default can be managed by tailoring financial terms to the risk profile and expected cash flow of the project concerned. For large and complex projects it is becoming common to blend different types of finance (commercial loans, concessionary loans, grants, equity) to achieve an acceptable overall mix.

There is a feasible approach to financing in the face of unknowns and risks. It involves a mixture of efficiency measures, review of standards and technological options, improved rates of collection, better cost recovery from water users, more predictable government subsidies and ODA, and the intelligent use of such basic revenues to attract repayable funding sources using the array of risk-sharing devices now available.

Chapter 13. Responses to risk and uncertainty from a water management perspective

There are no responses to risk and uncertainty that can be universally applied. However, by examining approaches that have been tried by others it is possible to learn from one or more that have succeeded or failed elsewhere under different circumstances. These responses have usually involved the use of various tools to identify and evaluate alternative water resources plans, policies, infrastructure designs and operating rules applicable to different regions of the developed and developing world.

One of the most direct ways of reducing uncertainty is to generate new knowledge or understanding of conditions governing water availability and quality in the present and in the future. Data collection, analytical capacity and predictive ability are all required to reduce uncertainty and therefore to facilitate decision-making about allocations, uses, mobilization and treatment. While the risk to water is not reduced, it is better understood.

Adaptive management strategies allow changing course based on new insights, help establish and sustain institutional settings and technological systems that are flexible and error-tolerant, and offer a framework for transparent decision-making processes. Funding a diversity of water storage projects, from small-scale rainwater tanks and larger-scale dams to systems that artificially recharge groundwater aquifers, to improving the soil so it can hold more water, is one option to meeting the increased need for storage. Stored water in times of drought can lead to increased food security. Just as modern consumers diversify their financial holdings to reduce risk, smallholder farmers can use a wide array of 'water accounts' to provide a buffer against climate change impacts.

Limited water availability, growing and evolving demands, and competition among increasingly scarce financial and physical resources create difficult trade-offs for decision-makers who must plan effectively under considerable risk and uncertainty. Countries can take precautionary or status quo approaches towards addressing risk and uncertainty, and these reflect the trade-offs they are willing to make to address risk and uncertainty. Policy changes only occur when the costs of maintaining the status quo exceed the transaction costs of implementing change. However, not all trade-offs need be negative. There are indeed examples of win–win situations where addressing risks and uncertainties in and outside of the water realm have led to multiple multi-sectoral benefits and to benefits for water in the long term.

Chapter 14. Responses to risks and uncertainties from out of the water box

Many of the problems faced within the water sector are caused by decisions made in other sectors, while many of the solutions to water problems can also be found within these sectors. Most decisions, within or outside the water world, involve some form of risk management. Anticipation of future benefits or threats is an integral part of sectoral decisions and business decisions alike. These decisions do not always take water into consideration, but often have an impact on water – and an impact on the types of decisions and reactions that water managers have to choose from.

Beyond the provision of water for basic human needs, such as food, drinking and hygiene, many development efforts have an impact on water risks and uncertainties. In most cases, more development means more water use, and more water pollution arises from higher levels of economic growth.

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Choosing diverse economic growth pathways could help to address risks and uncertainties related to water availability; however, very few countries have the option to do so because the trade-offs and political costs are so high and immediately felt.

In some cases, green growth entails turning a development challenge – for example, lack of access to chemical fertilizer – into a sustainable development opportunity. Following this model, existing water scarcity could provide a basis for technological innovation to help countries leapfrog towards greener growth, while avoiding the common risks faced by other countries. Climate change represents one of the greatest uncertainties currently facing human society. At the global level, there may be a high degree of likelihood for certain types of impact such as temperature increases and sea level rise; however, impacts at the local level are far less predictable.

Most business decisions are based on an approach to risks and uncertainties. Decisions on investments and modes of production make presumptions about the future. Many decisions that are uniquely motivated by the financial bottom line can also provide effective means of reducing risks and uncertainties related to water.

Government policies such as taxation rates, or fiscal incentives for attracting investment and business in a given location, while legal frameworks can go a long way to reducing uncertainties by providing boundaries for the investment context.

Governments may choose to attract investments that provide the highest value for water units, although examples of such types of decision remain unfortunately rare.

Tools such as the proper pricing and valuation of water resources can drive business decisions, particularly when water is a key input in production. They can also help to highlight trade-offs, costs and benefits/co-benefits that would otherwise not be apparent to business owners.

Win–win benefits between water and health planning can be found as the world's concern over pandemics and rapidly transmissible animal and human diseases increases. Because water acts as a vector of transmission or as a determining factor in the prevalence of certain transmissible diseases, efforts to prevent (or prepare for) global pandemics could generate benefits for managing risks and uncertainties related to water.

A number of international organizations highlight the water–food–energy nexus as illustrating the most difficult choices, risks and uncertainties facing policy-makers today. Examples abound of the various intended or unintended consequences of favouring one pillar over the other (e.g. food security versus energy security). A key challenge is to incorporate the complex interconnections of risks into response strategies that are integrated and take into account the many relevant stakeholders.

Insurance is of one of the oldest risk mitigation mechanisms – one that is applicable to all sectors, but that also helps to reduce the impacts of water-related risks. Index-based (or parametric) insurance is also emerging as a potentially powerful tool for risk management in all sectors.

Water treaties or agreements regarding water allocation in shared transboundary basins are multiplying, and are often quoted as having side benefits for reducing other risks, through the establishment of trust-building mechanisms and a certain amount of predictability in stakeholder behaviours.

Agreements and treaties signed for purposes other than water may help reduce risks and uncertainties regarding water, particularly where they provide mutual assurance of the other party's behaviour regarding natural resource use.

INTRODUCTION

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No water users, anywhere in the world, can be guaranteed they will have uninterrupted access to the water supplies they need or want or to the water-derived benefits from key developmental sectors such as agriculture, energy and health. Examples from around the world warn us that disregard for the central importance of water will eventually lead to breakdowns in the socio-economic and environmental systems so vital to the prosperity of all countries and their citizens.

While it is true that all aspects of social and economic development – often referred to as the *food–energy–health–environment 'nexus'* – depend on water, that is only half of the truth; the relationship is one of interdependency. All of the activities that drive development also shape important political and economic decisions that influence how water resources are allocated and managed, all of which often has substantial impacts on the quantity and the quality of the water available, and thus on other developmental sectors. Indeed, all of the sectors of the nexus are interlinked through water.

The combination of growing populations, increasing demands for resources associated with improving standards of living, and various other external forces of change are increasing demand pressures on local and regional water supplies required for irrigation, energy production, industrial uses and domestic purposes. These forces are undergoing rapid, accelerating and often unpredictable change, creating new uncertainties for water managers and increasing risks to all developmental sectors of the nexus through water. At the same time, climate change is creating new uncertainties with regard to freshwater supplies and to the main water use sectors such as agriculture and energy, which will in turn exacerbate uncertainties regarding future demands for water. In summary, the determinants of change in water demand and supply are themselves undergoing unpredictable changes.

Water is a vital component in the production of all goods and commodities, particularly food, and is thus embedded in marketed goods. Globalization of trade means that all countries and companies (consciously or unconsciously) are involved in the 'import and export' of virtual water and therefore share some responsibility for the local and regional impacts associated with international trade (including increasing scarcity and pollution) and the foreign investment protection system. As water demand and availability become more uncertain, all societies become more vulnerable to a wide range of risks associated with inadequate water supply, including hunger and thirst, high rates of disease and death, lost productivity and economic crises, and degraded ecosystems. These impacts elevate water to a crisis of global concern.

This fourth edition of the *World Water Development Report* (WWDR4) drives home the point that *all water users are – for better or worse and knowingly or unknowingly – change agents* who affect and are affected by the water cycle. It presents the case that, in today's world, a 'business-as-usual' approach to water management is tantamount to blind neglect of the ecosystems that sustain life and well-being. Past attitudes – which in many cases were of an expectation of governments to manage water as a 'sector' while decision-makers in other true sectors (food, energy, health and others) paid little attention to how their actions affected the water cycle (and other users) – have created a disconnect between policies and actions, and the role of managing both their consequences. The lack of interaction between the diverse communities of users, decision-makers and isolated water managers has caused serious degradation of the water resource and increased the risks to all the other sectors that depend upon it.

Perhaps the most troubling aspect of this assessment is that the rate of change now seen across the water cycle leaves water experts somewhat perplexed; history is no longer a reliable means of predicting future water demand and availability. In admitting that current understanding of the various pressures being placed on the water cycle is akin to islands of knowledge in a vast sea of unknowns, the WWDR4 also sets a challenge for all water users and the full spectrum of leaders and decision-makers to invest in building and sharing knowledge about how their actions affect water quality, quantity, distribution and use. Only through such a collective effort can ways be found to reduce uncertainty and manage risk to balance and optimize the many fundamental benefits provided to society through water.

As discussed in the WWDR3, globalization processes have brought benefits to billions of people, but have in large part left the 'bottom billion', in which women and children are disproportionally represented, marginalized and most vulnerable to existing risks. Learning how to equitably balance the many benefits, from local to global, derived from water will be a necessary key for change. If measures taken to deal with water-related issues do not explicitly incorporate equity issues, the poorest and the most underprivileged people are likely to continue being excluded from benefiting from the outcomes of these measures.

There are success stories of multiple stakeholders working together to turn rapid change in the forces that influence the water cycle into new opportunities to improve water provision, use and management. Presented throughout the report (and especially in Chapters 13 and 14), these examples of progress highlight the interaction of knowledge-building, policy, technology and greater input by a wider range of water stakeholders. Yet they also highlight the complexity of each and every situation – overemphasis on one aspect can unbalance the effort.

What's new in the WWDR4

The first two editions of the WWDR provided comprehensive assessments of the issues, trends and developments affecting and related to water on the basis of different 'challenge areas'. Under the coordination of leading United Nations (UN) agencies, these challenge areas were presented as individual chapters that described the state of the resource and ecosystems; major use sectors (human health, food and agriculture, industry, energy, human settlements); and management challenges (managing risks, sharing water, valuing water, enhancing knowledge and capacity, governance).

The third WWDR took a different approach (and structure) by providing a holistic analysis of the water domain while recognizing the externalities and their role on the state, use and management of the earth's water resources. It introduced the concept of external forces, providing a general description of the main 'drivers' of change and how these ultimately affect demand for – and thus have impacts on – freshwater resources. The key message of the report was that most decisions about water are not made by water managers, but by decision-makers outside the 'water box'; that is, actors from the spheres of civil society, business and government leadership, whose decisions concerning policy formulation, resource allocation and other political and operational issues affect water directly (through allocation and demand) and indirectly (through various drivers of change).

This fourth report builds on different elements of the first three editions and incorporates some entirely new aspects.

First, it reintroduces the twelve challenge area reports that provided the foundation for the first two editions. These were again prepared under the coordination of leading UN agencies. However, unlike the earlier versions, which provided a comprehensive overview of the issues, the new challenge area reports are shorter, with a focus on key challenges, recent developments and emerging trends, and on the external drivers and the pressures they place on water systems and how these can lead to a better understanding of uncertainty, management of risk and identification of opportunities. This is the context in which approaches to water management and policy are illustrated through specific examples, ranging from adaptive design criteria for infrastructure or demand management to institutional capacity development and policies for different developmental sectors.

Second, in addition to these challenge area reports, four new reports have been introduced, covering issues that had not been specifically covered under previous WWDRs: Water Quality, Groundwater, Gender, and Desertification, Land Degradation and Drought.

Third, in recognition that the global challenges of water can vary considerably across countries and regions, a series of five regional reports have been included, providing for the first time a regional focus to the WWDR4. These 'regional reports', which follow the same overall structure as the challenge area reports, were coordinated by the UN regional economic commissions.

Fourth, WWDR4 delves into a deeper analysis of the drivers described in the third edition, and examines possibilities for their future evolution. This analysis emanates from the results of the first phase of the World Water Assessment Programme's (WWAP) Scenarios Project, which is also described in WWDR4.

Fifth, this fourth edition of the WWDR incorporates a theme, 'Managing water under uncertainty and risk', which serves as the overarching topic for the report. This does not mean that the WWDR4 is about uncertainty and risk; rather, the WWDR4 examines current challenges to water resources, their use and management through the lens of uncertainty and risk. The WWDR4 considers the uncertainties associated with different external drivers and looks at managing the risks emanating from within and outside the water box, thus further building on the holistic approach taken in the WWDR3.

In summary, building on the comprehensive approach taken in WWDRs 1 and 2, and the holistic view taken in WWDR3, this fourth edition gives an account of the critical issues facing water's challenge areas and different regions and incorporates a deeper analysis of the external forces (i.e. drivers) linked to water. In doing so, the WWDR4 seeks to inform readers and raise awareness of the new threats arising from accelerated change and of the interconnected forces that create uncertainty and risk – ultimately emphasizing that these forces can be managed effectively and can even generate vital opportunities and benefits through innovative approaches to allocation, use and management of water.

Structure and content

The WWDR4 is separated into four parts. Part 1, 'Status, trends and challenges', provides an overview of recent developments, emerging trends and key challenges, including the external forces driving these and the uncertainties and risks created by the drivers. Part 2, 'Managing water under uncertainty and risk', is the thematic part of the report in which decisions affecting water, from management and institutions to allocation and financing, are investigated through the lens of risk and uncertainty, with particular emphasis on climate change and other drivers of change. Part 3 (Volume 2), 'Knowledge base', contains each of the challenge area reports prepared by UN-Water agencies and the regional reports prepared by the UN regional economic commissions – from which much of the material in Parts 1 and 2 was extracted – as well as other supporting documents. Like the earlier editions, the WWDR4 also contains case studies, Part 4 (Volume 3). The 15 country-level case studies describe the progress made in meeting water-related objectives, as well as some obstacles leading to lingering and in many cases worsening problems, showing that there are lessons to be learned from success stories as well as from failures.

The WWDR4 opens with Chapter 1, which describes the global dimensions of water and underlines the need to move beyond the concept of water as a sector. It discusses water's central role and cross-cutting nature in achieving various developmental targets, a reality that is evolving in key international processes such as the United Nations Framework Convention on Climate Change (UNFCCC) negotiations and the preparatory work leading up to the Rio+20 Conference of the UN Commission for Sustainable Development (CSD), or being adequately implemented in national frameworks.

Part 1 begins with Chapter 2, which focuses on the key sectors of water demand: food and agriculture, energy, industry, and human settlements. In addition to reporting recent trends and developments, this chapter describes the pressures for the main drivers, the uncertainties and risks related to each sector, projections on future demands (where possible) and possible response measures. The chapter concludes with a section on ecosystems as a 'user' of water, arguing that water demand by ecosystems is to be determined by the water requirements to sustain or restore the benefits for people (services) that we want ecosystems to supply.

Chapter 3 looks at the supply-side aspects of the water resources equation. Focusing on information provided in previous WWDRs, the chapter examines the role of large-scale climate drivers in distributing the earth's water resources over time and space. Two very important storage-related issues, groundwater and glaciers, are addressed here in terms of their vulnerability and the long-terms risks that may evolve from over-exploitation (groundwater) and from climate change (glaciers). The chapter concludes with an examination of the most pressing water quality issues and the risks these can engender.

Chapter 4 focuses on the benefits received through water in terms of human health and ecosystems and the challenges faced from natural hazards and desertification. These are examined in terms of current trends and hotspots, with uncertainties and risks associated with the main external drivers, and response options. The chapter includes a section focusing on gender-related challenges and opportunities and concludes with an examination of the current global water balance, describing the role of water as the nexus for sectors related to development and poverty eradication.

Chapter 5 describes how different water management systems and institutions function, looks at the challenges they face, and examines the important role of developing knowledge and capacity in addressing increasing uncertainty and risk.

Chapter 6 explores the need for better data and information for improved decision-making. The chapter describes the value of focusing on a small set of specific data items from which myriad indicators of performance can be developed, and highlights several promising options that, if properly implemented, could begin providing highly valuable information for water managers, institutions and decision-makers inside and outside the water box alike.

Chapter 7 presents a summary of each of the five regional reports contained in Part 3/Volume 2: Africa; Europe and North America; Asia-Pacific; Latin America and the Caribbean; and the Arab and Western Asia region. Each region is examined in terms of the driving forces and pressures on water resources, the main challenges, risks and uncertainties associated with these, hotspots, examples from responses to the challenges, and potential response options. The chapter (and Part 1) closes with an examination of the interlinkages between different regions and global challenges, which describes how actions in one part of the world can create negative impacts, as well as opportunities, in other parts of the world.

Part 2 begins with Chapter 8, which introduces some of the basic concepts of uncertainty and risk, including thresholds, tipping points and nonstationarity and what they mean in terms of water management, decision-making and policy formulation. Different principles and approaches to dealing with uncertainty and risk are presented with examples of their strategic applications.

Chapter 9 builds on the analysis of the main external forces (i.e. drivers) that were first introduced in the WWDR3. It includes an examination of the possible evolution of ten key drivers and the uncertainties and risks associated with them. It also reports on the results from Phase I of WWAP's World Water Scenarios Project, demonstrating the complexity of the interlinkages between these drivers of change. The chapter concludes with short examples that illustrate the possible futures that could arise from a water-centred scenario development exercise.

Chapter 10 focuses on the values of water, its benefits and its allocation. It sets out the elements of an economic case for investment in water and for reforming its development and management, starting with the overall benefits of water to an economy, and proceeding to consider the value of water in the various parts of its cycle. It shows how these benefits and values can be used to inform policies for the allocation and use of water in situations of growing resource pressures, uncertainties and associated risks.

Chapter 11 describes a set of different tools for leaders in government, the private sector and civil society who make most of the important decisions impacting water. Important instruments to support decision-making include forecasts and scenarios, as combining a range of forecasts of possible futures allows for more robust decision-making. A key tool to initiating the much-needed adaptation, proactive adaptive integrated water resources management (IWRM), is also presented. The chapter closes with a focus on ways institutions can be reformed to better deal with uncertainty and manage risk.

Chapter 12 builds on the case made in Chapter 10, showing that water development is key to sustainable development and an integral part of a green economy, and explaining how increased financing is necessary for all facets of water development, ranging from 'hard' infrastructure to equally important 'soft' items such as capacity; management; data collection, analysis and dissemination; and regulation and other governance issues. It examines efforts to help reduce the funding gap through internal efficiency and other measures; improve the generation of revenues from users, government budgets and official development assistance (ODA); and use these flows to leverage repayable finance such as bonds, loans and equity.

Chapter 13 presents a set of responses to risk and uncertainty from a water management perspective. Examples of reducing uncertainty are provided in terms of monitoring, modelling and forecasting to reduce uncertainty and understand risk; adaptive planning; and proactive management. Examples of reducing exposure and minimizing risk are also presented in relation to investments in infrastructure and environmental engineering. Finally, examples of trade-offs in water decision-making are presented.

Part 2 concludes with Chapter 14, which focuses on responses to risks and uncertainties from outside the water box. Examples are provided of how water can be affected (positively or negatively) through actions and policies aimed at reducing poverty and promoting green growth, responding to climate change (in terms of adaptation and mitigation), informing business decisions and managing sectoral risks. The chapter closes with approaches to mitigating risks and uncertainties, with a look at the roles of insurance, treaties and multi-sectoral cooperation.

CHAPTER 1

Recognizing the centrality of water and its global dimensions

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Italy: Countryside around Siena, Tuscany (43°19' N, 11°19' E)

Water is an essential resource required for sustaining life and livelihoods: safe water is required for drinking, hygiene and providing food; and adequate water to produce energy and support economic activities such as industry and transportation. Water in the natural environment ensures the provision of a multitude of ecosystem services to meet basic human needs and support economic and cultural activities. For too long water has been an issue that is at once everywhere and nowhere: it is the lifeblood of our planet and of the human societies that flourish upon it, but is frequently taken for granted, with decisions at all levels and across all sectors made without full consideration of the potential impacts on water resources and other water users. The challenge for twenty-first century governance is to place water at the heart of decision-making at all levels – horizontally across departments and sectors, and vertically at local, national, regional and global scales. Two prerequisites are essential to this happening.

First, *it must be understood that water is a natural resource upon which all social and economic activities and ecosystem functions depend.* It cuts across and affects more aspects of life than can be easily listed or categorized. It is a basic amenity of life, as well as being indispensable for other necessities: as an input to agriculture for food, fibre, feed and biofuels, the production of energy, and for industrial and manufacturing processes for multitudes of products. Water also has tradable aspects – both directly, for example, through pipes and bottles, in tankers and vessels, and indirectly or 'virtually' through products. In many contexts it is understood as a commodity although with many characteristics of a public good. Understanding the multiple aspects and roles of water is crucial to governing it effectively.

Second, *greater recognition is needed of the fact that water is not solely a local, national or regional issue that can be governed at any of those levels alone.* On the contrary, global interdependencies are woven through water, and decisions relating to water use on a local, national or regional level often cannot be isolated from global drivers, trends and uncertainties. Impacts on water resources are driven by factors both outside the 'water box' and, importantly, outside the 'decision-making box' of local, national and regional actors. The recognition that water is an ubiquitous cycle, tapped into by development at all levels, has implications for the processes instituted for governing water at local, national and regional levels, for sharing expertise, and moving towards more robust water management in different locations.

Some global dynamics and drivers, such as climate change and patterns of global trade or foreign investment regimes, cannot be dealt with solely at local, national or regional levels. Recognition of these *global dimensions* at the country level may influence the kinds of institutional arrangements necessary at the international level to address water-related challenges that demand an international response. The United Nations Conference on Sustainable Development (UNCSD) in 2012 and its subsequent plan of action[1] offer an opportunity for countries to advance discussions in this area, as do the United Nations Framework Convention on Climate Change (UNFCCC) in its negotiations on climate change mitigation and adaptation and the post-2015 processes surrounding the Millennium Development Goals (MDGs). Other relevant processes include Ramsar and the conventions on biodiversity and desertification. Forums and groups of formal and semi-formal nature such as the G8, G20, the World Economic Forum, the World Water Forum, and the World Social Forum also have an impact on global thinking.

This chapter explores these observations – that water is a natural resource critical to socio-economic development, and that some dimensions of water management are global. These factors sometimes demand global responses in addition to local, national and regional governance. Population growth, technology, changing lifestyles and increasing consumption and climate change, among others, introduce uncertainty to water management at both local and global levels.

1.1 Beyond the concept of water as a sector

Water is a necessary component for all major socio-economic sectors, contributing to each in different ways. Agriculture requires large quantities of water for irrigation as well good quality water for various production processes. Energy requires water for powering turbines (hydroelectricity), cooling power plants (thermal and nuclear electricity) and growing biofuels. Access to safe water supplies and basic sanitation are necessary for maintaining public health, and water is needed to support healthy ecosystems, which in turn provide critical environmental goods and services. The benefits from each of these sectors are provided through water.

A core focus of the third edition of the *World Water Development Report* was the impact on water resources of decisions taken outside the 'water box'. Planning for public health, urbanization, industrialization, energy production and agricultural development – to name but a few areas – is all too often conducted in isolation from water ministries and water managers. Furthermore, water demands and uses are often managed in silos with each focused on meeting specific developmental objectives, rather than as part of an overarching and strategic framework that balances different water uses in order to optimize and share its various benefits across society and the economy. This fragmentation increases risks to the sustainability of water resources as well as to the different development objectives that depend upon (and may be in competition for) limited supplies. Climate change exacerbates this problem still further. Climate change impacts on water resources, as well as the 'drivers' of demand, stand to turn water from an intermittent problem to an acute one in many parts of the world (Steer, 2010), making the case for consultation with actors outside the water box even more compelling.

The job of delivering adequate water for social, economic and environmental needs is often understood as the preserve of the 'water sector', which is expected to provide the appropriate infrastructure and channel water in the right direction. Yet in reality, water cuts across all social, economic and environmental activities. As such, its governance requires cooperation and coordination across diverse stakeholders and sectoral 'jurisdictions'. Furthermore, water availability must be understood within the context of the hydrological cycle, which is influenced by multiple factors, trends and uncertainties that extend beyond a narrow sectoral focus. This principle has been captured to a great extent by the movement towards integrated water resources management (IWRM), a governance framework for water resources that seeks to manage water across competing uses and needs – including agriculture, energy and industry – as well as water for basic human needs and ecosystem functions (see Chapter 5). Yet progress towards such governance frameworks has been slow, as operationalizing the principle of IWRM necessitates institutions that facilitate discussion and decisions on the targets of society, and the allocation of water resources across sectors to meet them. In the absence of institutionalized IWRM (or a similar coordinating mechanism), growing recognition of the water-food-energy-health-environment *nexus* concept can help raise awareness among managers responsible for planning in different water-dependent sectors of the broader implications of their actions, including their water use, on the resource and other users.

It is true that water unites a community of experts, managers, officials and other stakeholders who are tasked with managing the resource effectively and responding to increasing demand. As such, its status as a sector cannot be completely denied. The crucial factor for water governance is therefore the recognition that water is not *only* a sector, but also a necessary element that provides benefits for all sectors, thus requiring active consultation with, and coordination among, the sectors and communities that depend upon it. In particular, members of the water community have the duty to inform and provide guidance to decision-making and to regulatory authorities on how to use and manage the resource sustainably, so as to optimize and share its many benefits and minimize conflicts. In short, addressing water challenges necessitates interventions across an entire economy, undertaken by strong institutions with the authority, capacity and leadership to take a proactive rather than a reactive role in water management, and to drive the productive use of water across sectors within the limits of social and environmental sustainability (Steer, 2010). The importance of political leadership in establishing, reviewing and maintaining the frameworks to manage these competing demands cannot be understated. Some of the areas where this is particularly critical are outlined in this section.

1.1.1 Food

Water for irrigation and food production constitutes one of the greatest pressures on freshwater resources. Agriculture accounts for around 70% of global freshwater withdrawals (reaching up to 90% in some fast-growing economies). Global population growth projections of 2 to 3 billion people over the next 40 years, combined with changing diets, result in a predicted increase in food demand of 70% by 2050 (see Section 2.1 and Chapter 18). However, as the largest user of water, food production also represents the largest unknown in terms of future global water demand, for several reasons.

First, it is difficult to predict how diets in different countries and regions will evolve over the next few decades, and therefore what type of food (with its varying demands for water) will be produced. The quantity of biofuel that will be needed is also unknown, or how this demand will affect food production through increased competition over land and water. The extent to which technological improvements in agricultural water productivity ('crop per drop') will affect future water demand is extremely difficult to predict. Finally, because of climate change, there are many uncertainties concerning how much water will be available where and when.

In the short-term, increased demands for food represent a significant economic opportunity for farmers and agricultural producers all over the world, especially in developing countries whose economies are often highly dependent upon agricultural production and export. There are plenty of sustainable ways of responding to increased food demand, such as drought resilient crops, incentives for more efficient irrigation and water usage, removal of subsidies encouraging inefficient water use, and regulatory frameworks to control water pollution from excess fertilizer use (WEF, 2011). Dialogue between water managers and agricultural planners is crucial to ensuring that the right combination of the above is identified and properly implemented, so as to reduce uncertainties and risks related to food and water security. This dialogue must include stakeholders who make a living from agriculture (including biofuels), at all levels, in order to inform the decision-making authorities about their current and future allocation needs.

1.1.2 Energy

The relationship between water and energy is reciprocal (see Section 2.2 and Chapter 19). Energy is required for humans to make use of water – to lift, move, process and treat it at every phase of its extraction, distribution and use (USAID, 2001). Out of all energy produced globally, 7% to 8% is used to lift groundwater and pump it through pipes, and to treat both groundwater and wastewater (Hoffman, 2011) – a figure that rises to around 40% in developed countries (WEF, 2011). Desalination, the process by which seawater is converted to freshwater, is especially energy intensive. The treatment of wastewater also requires significant amounts of energy, and demand for energy to do this is expected to increase globally by 44% between 2006 and 2030 (IEA, 2009), especially in non-OECD countries where wastewater currently receives little or no treatment (Corcoran et al., 2010).

> "The crucial factor for water governance is … the recognition that water is not *only* a sector."

Conversely, water is needed to produce and make use of energy. It is required for cooling in the generation of thermal and nuclear electricity, and is necessary for alternative or renewable forms of energy such as hydropower (as a direct input), as well as concentrated solar energy. Biofuels represent an additional demand on water resources, and also compete with food for limited water and land. In 2009, the number of people without access to electricity was 1.4 billion or 20% of the world's population. Global energy consumption is expected to increase by about 50% between 2007 and 2035 with non-OECD countries accounting for 84% of this increase (IEA, 2010*b*). The need to increase energy supplies to meet rising populations and living standards, as well as presently unmet demand, creates several unknowns: which energy mix will be used (and where), and how much more water will be needed to generate this additional energy? These unknowns add to the other major uncertainties regarding future demands for water. Climate change further complicates the issue because mitigation and adaptation imperatives have energy implications (see Section 1.2.1). As the pressure to invest in renewable energy intensifies in an effort to achieve mitigation objectives, there may be significant trade-offs in relation to water resources.

The relationship between water and energy illustrates the centrality of water in relation to other developmental sectors. For example, health problems induced by a lack of access to clean energy (e.g. cooking inside on wood burners) often go hand-in-hand with diseases caused by lack of access to safe drinking water (see Section 4.1 and Chapter 34). How can governments simultaneously deliver expanded energy access while also increasing access to water for both personal and productive uses? Enhancing efficiency in both energy production and the extraction, delivery and treatment of water will be critical, as will the choice of energy source according to context. Biofuels are an increasingly prominent component of the energy mix, as exemplified by the EU target for biofuels to constitute 10% of transport fuel by 2020 (EU, 2007). This target has been hotly debated as it acts as a driver for conversion of land from food to biofuel production, placing upward pressure on food prices, and in some cases leading to the conversion of forest ecosystems to land to 'grow' biofuels. Estimates vary, but even modest projections of biofuel production suggest that if by 2030 – as the IEA suggests – just 5% of road transport is powered by biofuels, this could amount to at least 20% of the water used for agriculture globally (Comprehensive Assessment of Water Management in Agriculture, 2007). Of course, should alternative technologies for biofuel (e.g. photobioreactors for algae) become available on a large scale, these projections could change dramatically, further illustrating the increasing uncertainties related to future water demands from different, often interconnected, demand sectors.

1.1.3 People

Beyond physiological hydration (roughly 60% of human body weight is water) water is necessary for meeting most of our basic physiological needs and provides us with myriad additional benefits (see Chapter 4). Access to drinking water supply and sanitation (WSS) services is key to meeting many of these needs. The importance of safe drinking water and sanitation for human health, well-being and socio-economic development is well established and is, quite understandably, a recurring issue in this report.

WSS is a 'service sector', which like electricity is supported by different institutional arrangements and financial mechanisms to provide people with a set of basic services. In fact, the WSS services sector is so important that it has led to a common and reoccurring misperception: that water and the WSS services sector are synonymous. This is not true. As is the case for agriculture, energy and other sectors, water is the resource upon which the sector is based – in this case, it is both the substance *and* the medium through which water supply and most urban sanitation services are provided. This can (and has been) the source of some confusion, even among those in the water community. But it is important to differentiate water (which is a fundamental natural resource that needs to be managed and protected) from WSS services, which are services that need to be *provided*.

Providing increased access to WSS services raises some interesting questions with respect to uncertainties. For example, will sanitation always be closely linked to water – or will it evolve to capturing urine and excreta for productive uses? Will there be more capture of rainwater or reuse of wastewater for gardens and urban green spaces? This would naturally make a major change in household water consumption.

Many of water's benefits to people are imparted through the services provided by the WSS services sector. Direct benefits to living standards include health and dignity. These also lead to indirect benefits such as increased access to higher levels of income and education, as well as the promotion of gender equality and empowerment of women. But there are also several benefits that are not necessarily related to WSS services. For example, water is indispensible for 'income sources for both smallholders and landless people, such as raising livestock. Trees and shrubs for fuel wood, timber, fruits and medicaments need water. Catching fish for family consumption can provide a major source of protein for poor households and provides incomes for small artisan fishermen and women. Water is also needed for various small industries and crafts, like brick-making, pottery, or beer-making.' (WWC, 2000, p. 15). Transportation and recreation are yet other examples of the benefits we receive through water.

Water can also help to shape our values and ethics, as individuals or as part of wider communities that can work together to manage the resource and share its benefits. Involving end users, particularly women, in water management contributes to optimizing benefits from water projects (see Section 4.2 and Chapter 35). It should also be remembered that, in Africa, women are the ones who produce 60% to 80% of the food for their families (FAO, n.d.). Water and energy are needed for this and it is imperative that women have access to water for irrigation from surface, ground and rainfed sources, generally at a small scale. This is sometimes a function of land and water rights, but also requires that local water managers recognize women's water needs outside of the household. Water managers can work with men and women who use WSS services to find out what they need and what the best solutions are. Urban and rural communities can make practical contributions regarding new approaches to urban planning and land use, and can identify the most suitable technical solutions, including technology, the location of various facilities, and the most appropriate sources of water, according to what they can afford. The community can support their water facility through resource mobilization and labour for construction, operation and maintenance.

1.1.4 Ecosystems

Ecosystems provide a multitude of benefits to humans (ecosystem services); for example, products such as food, timber, medicines and fibre, regulating climate and supporting nutrient cycling, and soil formation and deposition. Providing water, as a resource for direct use, is also an ecosystem service in terms of both its quality and its quantity. Ecosystems, in turn, also depend on water in order to function; when they are stressed the benefits are reduced or eliminated (see Sections 2.5 and 4.3 and Chapter 21).

The water cycle is a biophysical process. Without life on earth the water cycle would still exist, but be quite different. Ecosystems underpin the sustainable quantity and quality of water available: for example, the life in soils regulates water storage there and nutrient cycling, supporting all terrestrial life (including food production); forests (through plant transpiration) regulate local and regional humidity and precipitation; wetlands (and soils) regulate the extremes of drought and flood.

The role of ecosystems in the water cycle has two interrelated implications for water management. The first is that water must be allocated so as to allow ecosystems to continue to deliver the level of benefits we need (e.g. through maintaining environmental flows).[2] The second is that ecosystems can be proactively managed (other than by allocating water to them), through, for example, conservation or rehabilitation, in order to deliver what we need to meet water-related objectives. For example, forests are very good at delivering clean water, and wetlands at regulating floods and restoring soil functionality, a key mechanism to combat desertification.

The stability of ecosystems is under increasing threat from unsustainable patterns of human consumption, development, and climate change across the globe. The Millennium Ecosystem Assessment states that the 'primary indirect drivers of degradation and loss of inland and coastal wetlands have been population growth and increasing economic development' (MA, 2005). Examples of ecosystem damage largely coincide with areas of high water stress, such as in West Asia and the Indo-Gangetic Plain in South Asia, the North China Plain and the high plains in North America (Arthurton et al., 2007). Excessive withdrawal of both surface and groundwater over the past 50 years for agriculture, energy, industry and urban growth has led to a situation in many parts of the world where water abstraction exceeds the threshold of water renewability in the river basin, resulting in widespread damage to ecosystems (Molle and Vallée, 2009). The precise amount of water required to sustain a given ecosystem over a certain period is often unknown, and allocation decisions would also depend on the type of ecosystem services to be maintained. As this is a societal judgement that can also vary over time, it adds to the uncertainties in anticipating future water demands.

1.1.5 Water-related hazards

Many of the impacts of natural hazards on socio-economic development occur through water (see Section 4.4 and Chapter 27). Between 1990 and 2000, in several developing countries, natural disasters caused damage representing between 2% and 15% of their annual GDP (World Bank, 2004; WWAP, 2009). Water-related hazards account for 90% of all natural hazards, and their frequency and intensity is generally rising. Some 373 natural disasters killed over 296,800 people in 2010, affecting nearly 208 million others and costing nearly US$110 billion (UN, 2011).

The increase in natural disaster losses over the past few decades is largely attributable to the increase in the value of exposed assets (Bouwer, 2011). While there is currently no evidence that climate change is directly responsible for increased losses associated with water-related hazards (Bouwer, 2011), it is expected to bring about an increase in the frequency of certain natural hazards, including floods and droughts (IPCC, 2007).

Water management plays a central role in reducing the risks of natural disasters. Water storage (via reservoirs, aquifer recharge or other means) is vital to combating the effects of drought, providing a supply buffer that

> "Managing water sustainably supports the overall objectives of a green economy or a green growth pathway, and also satisfies critical social imperatives."

can be made available for key beneficial uses during times of scarcity. Reservoirs can also serve to retain floodwaters, and are often an important component of physical flood defence systems, along with levees, weirs and dykes designed to prevent rivers from bursting their banks.

Such infrastructure forms part of a broader and integrated water management system (see Chapters 5, 11 and 12), which also include ecosystems and urban drainage systems, whose operation and maintenance (when available) reduce uncertainties and risks to water use sectors and development goals. Rising levels of uncertainty and risk associated with extreme events are indeed worrying, but must not become paralyzing. Quite the opposite: not knowing something implies opportunities to find out more and the notion of risk implies the existence of choices. It is possible to influence outcomes including minimizing risk or mitigating its impacts (see Chapter 8).

1.1.6 Water's role in greening economies and growth

Recognizing the centrality of water for sustainable development is crucial in the development of a green economy. In a green economy, the role of water in maintaining ecosystem services and water supply would be acknowledged, appreciated and paid for (UNEP, 2011). Direct benefits to society as a whole can be gained by increasing investment in water supply and sanitation, including investment in wastewater treatment, watershed protection and the conservation of ecosystems critical for water. New approaches, such as planning for adaptation to uncertain futures, the adoption of green technologies, improving the efficiency of water provision, and developing alternative water sources and forms of management (e.g. desalination, water recovery and reuse, payment for environmental services, ecosystem conservation, improved property rights) will play an essential role in enabling a cross-sectoral transition to a green economy. The consideration of full costs of service provision may also be an enabling factor, but this principle has often proven to be impractical in many situations as it can be difficult to implement in practice, especially in developing countries.

Managing water sustainably supports the overall objectives of a green economy or a green growth pathway, and also satisfies critical social imperatives of poverty alleviation, food and energy security, and health and dignity, through the provision of water and sanitation services. Investment in and protection and sustainable management of water resources, across society as a whole, allow significant steps to be made towards achieving a green economy that advances long-term human well-being within ecological limits (see Chapters 12 and 24). The way that water is managed and allocated has impacts across all areas of society and economy, and its governance must move 'from the pump room to the Boardroom' (Steer, 2010). Embedding water management as the central pillar of sustainable development requires institutions that facilitate discussion and decisions on society's targets and the allocation of water resources to optimize generation and equitable distribution of its many benefits. It is, then, the role of water managers to inform the process and do what is necessary to implement the decisions.

As conceptualized within a green economy, those benefitting from environmental services would be valued stakeholders, alongside other water users who would be recompensed to provide more equitably distributed benefits. The 'polluter pays principle' provides a basic model with which to achieve this, supported by robust and proactive regulation on a relevant river basin scale to identify polluters and enforce compensation for the restoration of environmental impacts. Furthermore, existing aspects of sound water policies related to poverty alleviation and gender equality are already supportive of the objectives of a green economy, whereby all water users have fair and equitable access to the benefits of maintaining a healthy environment. For example, the provision of water services to families in extreme poverty in Lima, Peru, within the framework of the Water for

All Programme, is estimated to have increased total disposable family income by 14% per month, resulting from lower water expenditures and reduced health care costs (Garrido-Lecca, 2010; see Box 1.1).

1.2 Beyond the basin: The international and global dimensions of water governance

The drivers of water use and availability (the impact of many of which is uncertain) are found not just outside the water box and beyond the sector, but also often in other nation states. Although water is distributed unevenly across the planet, it forms part of a global cycle – the hydrological or water cycle – which can be interrupted by actions and phenomena that take place beyond the nation state (e.g. regionally through upstream diversions and globally through the impacts of climate change). Other aspects of the global equation include the international distribution of certain water-related benefits (predominantly expressed through trade in agricultural products), the rising global demand for water, the limited availability of the resource at any one time or place, and the over-consumption of water and high-water content of goods and commodities in some developed countries. Building on these observations, this section addresses four prominent, interconnected factors that introduce a global dimension to water governance: climate change, transboundary basins, global trade and international investment protection, and equity.

BOX 1.1

Water for All Programme, Peru

In Peru, the Water for All Programme was designed not only as a mechanism for expanding the coverage of water supply and sanitation services, but also as a 'cost-based approach' to the alleviation of extreme poverty or indigence.

Once connected to the network, families living in extreme poverty, who previously bought water in drums, more than tripled their water consumption. However, their monthly spending on water decreased, resulting in a 10% increase in disposable income. The Programme also helped reduce gastrointestinal diseases caused by a lack of basic services and by inadequate sanitary conditions, with estimated additional monthly savings for families from lower health care costs – taking account only of the elimination of the episodes of acute diarrhoeal diseases – of about 4% per month (resulting in a total increase in disposable family income of 14% per month).

The aspiration of the Programme is that, by reducing unavoidable expenses, freeing up cash flow and increasing disposable income, it will ultimately generate a small amount of savings that will allow families to transition towards poverty levels that at least make inclusion in the formal market possible.

A potentially attractive feature of the Programme is that it has a once-off investment cost; the families themselves then pay for the service with only a small, pre-existing cross-subsidy that covers an initial consumption block. Therefore, in terms of sustainability and from a fiscal point of view, the Programme does not jeopardize its continuity or the beneficiaries' chances of escaping from extreme poverty.

Sources: Garrido-Lecca (2010, 2011).

1.2.1 Climate change

Climate change highlights the centrality of water in relation to a key global issue. First, because the worst climate impacts are delivered through a changing water cycle, and their avoidance requires global cooperation on a climate change agreement. Second, unavoidable climate change impacts through water in developing countries result in an obligation for developed countries to assist some in adapting to these impacts. Third, efforts to improve water governance arrangements are, in effect, the focus of climate change adaptation needs, and must be explicitly recognized as such in climate change funding. And last, climate change mitigation and adaptation responses are related because the carbon and water cycles are interdependent.

The Intergovernmental Panel on Climate Change (IPCC) states that 'water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change' (Bates et al., 2008, p. 7). People will feel the impact of climate change most strongly through changes in the distribution of water around the world and its seasonal and annual variability (Stern, 2007). The poor, who are the most vulnerable, are also likely to be affected the most (Stern, 2007). Climate change also leads to new uncertainties concerning future water demand through different water-using sectors. For example, global warming suggests increased energy demands for air conditioning, and higher evapotranspiration rates could increase future demands for agriculture.

The precise impacts of climate change through water, in particular locations, remain uncertain and are notoriously difficult to predict, especially at the local

“The carbon cycle (the realm of climate change mitigation) and the water cycle (the realm of adaptation) are interlinked: ecosystems require water to store carbon and by doing so impact water.”

or river basin level. Under different IPCC scenarios, regions may become ‘drier’ or ‘wetter’, as there are a variety of possible ways in which climate change may impact the hydrological cycle in different areas and at different times. What is certain is that the uncertainties generated by climate change add a global dimension to the challenges of water resources management, as efforts to effectively manage water locally may be impeded by climate-induced hydrological impacts or increasing demands. Efforts to limit negative climate change impacts occurring through the water cycle require collective, global efforts to reduce carbon emissions, which ‘go beyond the governance domain of water managers who operate at the local, national or river basin level’ (Hoekstra, 2011, p. 24). Indeed, discussions on the respective responsibilities and capabilities of states to reduce greenhouse gas (GHG) emissions are rightly conducted through the UNFCCC.

Even if the most ambitious GHG reduction agreement were to be implemented now, it would likely not prevent the world from experiencing a certain level of climate change. The interconnected nature of our global economy means, for example, that climate-induced water shocks in an important food-producing region may potentially have significant impacts on food security in other parts of the world. But the capacity to adapt to climate change impacts through the water cycle is extremely low, particularly in a number of developing countries, which may be facing increasing water scarcity, and where the adaptive capacity of institutions is often restricted by deficient design, low operational capacity, and insufficient human and financial resources. For these countries, which have contributed the least amount of GHGs, adaptation represents an additional financial burden that many find difficult to support without assistance from the most prominent GHG-producing countries.

The cost of adapting to the impacts of a 2°C rise in global average temperature could range from US$70 to US$100 billion per year between 2020 and 2050 (World Bank, 2010). Of these costs, between US$13.7 billion (drier scenario) and US$19.2 billion (wetter scenario) will be related to the ‘water sector’, predominantly through water supply and flood management. However, these estimates do not take account of the benefits water provides through other ‘sectors’ (food, energy, health, etc.) and is thus under-representative of the full value of the benefits that would be obtained from a greater focus on adaptation through water. Water’s central role in adaptation, and in socio-economic development in general, merits explicit recognition in the ongoing negotiations concerning Green Climate Fund (GCF)[3] and other financing mechanisms. Furthermore, infrastructure development, as well as the institutional reforms required to ensure the optimization of water’s benefits across various socio-economic sectors, should be considered as key components of climate change adaptation.

In mitigation terms, the appropriateness of global interventions and mechanisms relating to land use, notably forestry and agriculture should be analysed in ways that include their potential impacts on water in each context.

In recognition of the role that deforestation plays in contributing to global GHG emissions (estimates suggest between 20% and 25% of total emissions), the UNFCCC has explored options through its initiative on Reducing Emissions from Deforestation and Forest Degradation (REDD) (UN, 2009). REDD basically ascribes a value to the carbon sequestration potential of forests and calls on developed countries to transfer funds to developing countries to preserve those forests to help mitigate climate change. However, the relationship between water and forests is complex. While it is true that forests rely on water availability for their long-term sustainability through groundwater, surface water and precipitation, it is also true that forests play a central role in improving water quality and, by maintaining or improving soil infiltration and soil water storage capacity, they influence the timing of water delivery (Hamilton, 2008). Forests also play an important self-regulating role in the regional cycling of water by re-intercepting atmospheric water locally generated by evaporation and redistributing it over different parts of the forest (Hamilton, 2008). The key point is that the carbon cycle (the realm of climate change mitigation) and the water cycle (the realm of adaptation) are interlinked: ecosystems require water to store carbon and by doing so impact water.

Agriculture has in recent years also emerged as a potential area for carbon sequestration, and discussions have emerged as to whether sustainable agricultural practices that reduce 'business-as-usual' carbon emissions might be eligible for carbon credits. Yet water remains an under-recognized part of this equation. Farming practices that sequester more carbon usually do so by restoring soil functions and land cover, both of which require the conservation of soil water. The linkages between carbon, water and sustainable farming are therefore usually significant and mutually inclusive. A global market incentive for low-carbon farming, therefore, involves a significant water dimension. These examples serve to highlight the global and multi-disciplinary, interfaces of water governance in relation to climate change objectives.

A policy brief issued by UN-Water makes the case for water's role in adaptation to climate change (Box 1.2).

BOX 1.2

Climate change adaptation: The pivotal role of water

Water is the primary medium through which climate change influences Earth's ecosystem and thus the livelihood and well-being of societies. Higher temperatures and changes in extreme weather conditions are projected to affect availability and distribution of rainfall, snow melt, river flows and groundwater, and further deteriorate water quality. The poor, who are the most vulnerable, are likely to be adversely affected.

Adaptation to climate change is urgent. Water plays a pivotal role in it, but the political world has yet to recognize this notion. As a consequence, adaptation measures in water management are often underrepresented in national plans or in international investment portfolios. Therefore, significant investments and policy shifts are needed. These should be guided by the following principles:

- Mainstream adaptations within the broader development context
- Strengthen governance and improve water management
- Improve and share knowledge and information on climate and adaptation measures, and invest in data collection
- Build long-term resilience through stronger institutions, and invest in infrastructure and in well-functioning ecosystems
- Invest in cost-effective and adaptive water management as well as technology transfer
- Leverage additional funds through both increased national budgetary allocations and innovative funding mechanisms for adaptation in water management

Application of these principles would require joint efforts and local-to-global collaboration among sectoral, multisectoral as well as multidisciplinary institutions.

Source: An extract from the UN-Water policy brief Climate Change Adaptation: The Pivotal Role of Water, available at http://www.unwater.org/downloads/unw_ccpol_web.pdf (p. 1, Executive Summary).

1.2.2 Transboundary basins

Water is not confined within political borders. An estimated 148 states have international basins within their territory (OSU, n.d., 2008 data), and 21 countries lie entirely within them (OSU, n.d., 2002 data). In addition, about 2 billion people worldwide depend on groundwater supplies, which include to date 273 transboundary aquifer systems (ISARM, 2009; Puri and Aureli, 2009).

There are numerous examples where transboundary waters have proved to be a source of cooperation rather than conflict. The Food and Agriculture Organization of the United Nations (FAO) has identified more than 3,600 treaties relating to international water resources (FAO, 1984). The earliest recorded water-related international treaty is usually considered to be the one which concluded the first and only water war (between Umma and Lagash city states). Nearly 450 agreements on international waters were signed between 1820 and 2007 (OSU, n.d., 2007 data).

There are numerous examples of existing bilateral and regional water agreements, including the Great Lakes Water Quality Agreement (1978), the Convention on Co-operation for the Protection and Sustainable Use of the River Danube (1994) and the Agreement on the

Cooperation for the Sustainable Development of the Mekong River Basin (1995). The Indus Water Treaty, signed between Pakistan and India in 1960, has survived three major conflicts and remains intact today. Benefit sharing, as opposed to the sharing of water resources, represents a key positive aspect in transboundary cooperation, as exemplified by the Nile Basin Initiative's Socio-economic and Benefits Sharing Project (2010) that builds a 'network of professionals from economic planning and research institutions, technical experts from both the public and private sectors, academics, sociologists, and representatives from civic groups and NGOs from across the basin to explore alternative Nile development scenarios and benefit-sharing schemes'.[4] However, multiple and increasing drivers of water use and the uncertainties associated with them are likely to put existing transboundary agreements under significant strain. The increasing demand for water for agriculture, industry, energy and urbanization is likely to put pressure on transboundary relations as states may seek to make more river diversions, store more water and further exploit aquifers. The need to meet a 60% increase in demand for energy over the next three decades, combined with the imperative to invest in clean energy to mitigate climate change, is already making hydropower and biofuels critical parts of the development equation (Steer, 2010). Only 5% of total hydropower potential has been exploited in Africa (IEA, 2010*a*), where many hydropower sites are situated on transboundary rivers, thus providing significant opportunities for increased cooperation on benefit-sharing among neighbouring states.

The increasing pressures on transboundary waters require significant investment in political capital (Steer, 2010) so as to either renegotiate existing but inadequate transboundary arrangements where needed, or establish new ones that as yet do not exist. Despite the proliferation of agreements on transboundary water management, there remain numerous river basins and aquifers without adequate legal frameworks for cooperation. According to a recent study, 60% of the world's 276 international river basins lack any type of cooperative management framework (De Stefano et al., 2010).

The role of global guidelines and normative legal principles is critical in this regard. The UN Convention on the Law of the Non-navigational Uses of International Watercourses was adopted in 1997 after 27 years of development. The Convention establishes the rights and obligations between states relating to the management, use and protection of international watercourses, which includes groundwater. To date, only 24 nations have ratified the Convention and a further 11 are required for it to enter into force. The principles enshrined within the Convention, including those widely recognized as part of customary law, can still be used as helpful guidelines irrespective of ratification. Nevertheless, entry into force represents a vital step in the process of further clarifying and, where necessary, developing and adapting the rules of the game to emerging challenges, so that the Convention can effectively fulfil its roles of governing and guiding interstate relations. In Europe, the 1992 United Nations Economic Commission for Europe (UNECE) Convention on the Protection and Use of Trans-boundary Watercourses and International Lakes has been used as the basis for adoption of many bilateral and multilateral agreements. The Convention was amended in 2003 to allow accession to countries outside the UNECE region. The amendment is expected to enter into force in 2012, thereby making this successful framework available to all UN Member States. There is also emerging recognition of the governance dimensions of transboundary aquifers. The International Shared Aquifer Resources Management (ISARM) Programme is a UNESCO-led worldwide effort involving multiple UN agencies, which strive to draw attention to the issue.[5] The UN General Assembly reaffirmed in its sixty-sixth session on 9 December 2011 the importance of transboundary aquifers and the related Draft Articles. It adopted a resolution in which States are encouraged to make proper arrangements for transboundary aquifer management and UNESCO-IHP to continue its related scientific and technical support to the States. In addition, the General Assembly decided to put 'The Law of Transboundary Aquifers' on the provisional agenda of its sixty-eight session, in order to examine – among others – the final form to be given to the Draft Articles.

The unavoidable reality that water resources do not respect political boundaries demonstrates the supranational dimensions of water, and represents a compelling case for international cooperation on water management. Multiple and mounting pressures on water resources globally urge caution against complacency. A strong focus on resource protection, sustainability and benefit sharing between states through robust and fair basin, aquifer, estuarine and inshore arrangements and institutions, supported by a strong and solid system of international water law, will be critical in an impending era of global water resource constraints.

1.2.3 Global trade

Water is a truly global issue through its trade as 'virtual water' (also known as embedded water). This refers to the volume of water used in the production of a good or service. Through this process, countries engage in water trading through products rather than through the physical transportation of water itself, which is a difficult and costly exercise. As a result, billions of tonnes of food and other products that require water to produce are traded globally. Some water-scarce countries, including a number in the Middle East, have become net importers of virtual water, relying on the importation of agricultural commodities to meet the food needs of their growing populations. As per capita water scarcity grows, more and more countries may be increasingly incapable of feeding themselves with the amount of water they have available, and will thus have to make trade-offs in their economic, agriculture and trade policies. Other countries, including a number of European nations, are also net importers of virtual water due to the consumer tastes and demands of their populations for particular foodstuffs and products via imports (Hoekstra, 2011).

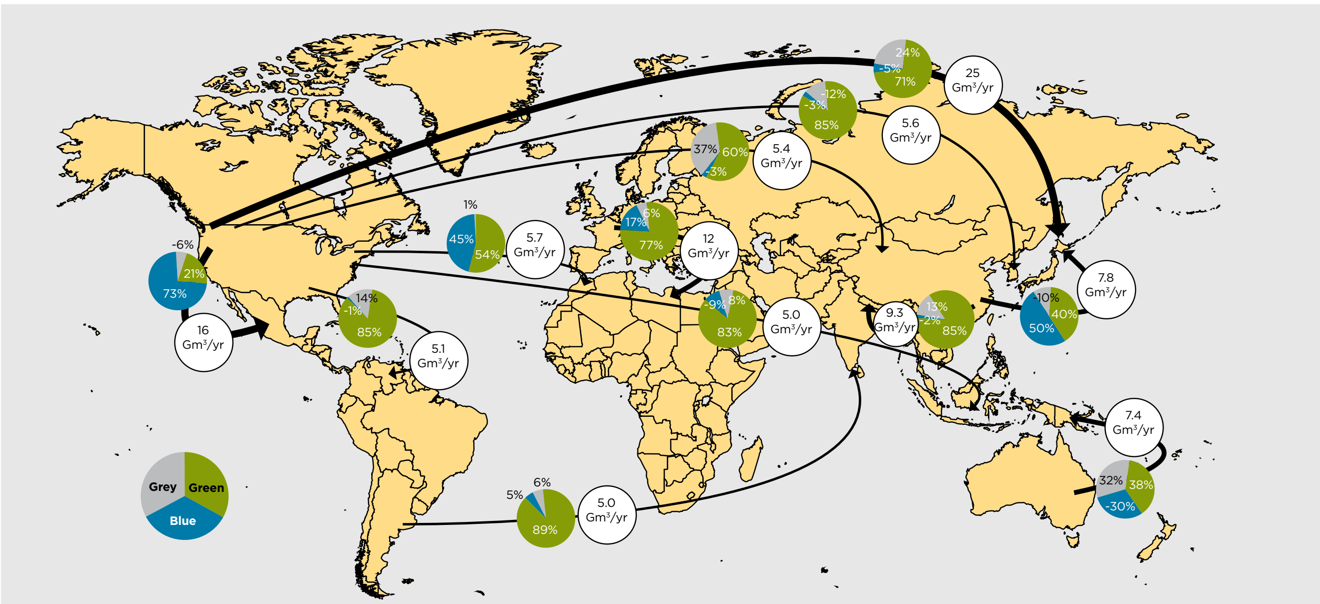
In many ways – at least at face value – virtual water trade is a process that represents a sensible and win–win realignment of the water needs of countries and their environmental and economic circumstances. Analyses show that, indeed, the trading of virtual water has in many cases led to certain efficiency savings. Figure 1.1 shows trade flows that save more than 5 Gm^3 per year. Export of agricultural products (mainly maize and soybean products) from the United States of America (USA) to Japan and Mexico represent the largest global water savings, accounting for over 11% of the total global water saving (Hoekstra and Mekonnen, 2011).

Although global water trade can lead to significant *national* water savings, through virtually transporting water from a place of relative abundance to a place of relative scarcity, trade alone cannot guarantee sustainable water management at the source. Indeed, as virtual water-exporting nations increasingly respond to global demand, the dimensions of responsibility for sustainable water management are subsequently elevated to a more complex and supranational relationship between consumer and producer.

One of the challenges to enhancing water efficiency and productivity is that there are no immediate, direct

FIGURE 1.1

Global water savings associated with international trade in agricultural products (1996–2005)



Note: Only the biggest water savings (> 5 Gm^3 per year) are shown.
Source: Mekonnen and Hoekstra (2011, p. 24).

> "As is the case with most globalization processes, virtual water trade can lead to a further marginalization of the world's poorest women and men."

incentives to actually do this. The incentives that are available are in turn influenced by global trade imperatives which are clearly beyond regulatory reach of water managers. If water-intensive products were traded only within the nation state then market-based policies to incentivise sustainable water management practices could potentially be instituted relatively easily, including perhaps a 'water scarcity rent' or through an 'internalization of externalities'; for example, incorporating into the cost of a product its negative impact on freshwater ecosystems and thereby incentivizing the producer to reduce or eliminate their environmental impact. But in a globalized economy it is a challenge to institute such policies on a national or a regional level as they may artificially increase costs of products from that area and make them uncompetitive.

The virtual water trade can provide opportunities for developing countries blessed with a relative abundance of renewable freshwater supplies to grow their economies by exporting increasing amounts of food, if they can afford the infrastructure to harness the water and there are no artificial barriers in international trade. Unfortunately, many countries still require some kind of financial support in order to develop this infrastructure and remain competitive within the global markets. Another troubling issue concerns developing countries that are water-scarce and whose people are too poor to buy imported food. As is the case with most globalization processes, virtual water trade can lead to a further marginalization of the world's poorest women and men.

The growing trend towards large land acquisitions,[6] which in some cases can lead to significant advances in infrastructure development, also raises some concerns about equitable distribution of benefits to the host country and its people. Although water shortages are an important driver of large-scale land acquisitions by investors, water is typically not explicitly mentioned in disclosed land deals. In the few cases where water is referred to, the amount of water withdrawals to be permitted is not specified. The rural poor end up competing for scarcer water with actors that are more powerful and technically better equipped to take control of the water. Potential inter-state tensions and conflicts, especially in transboundary basins, are also a cause for concern.

A subject relevant to the governance of water resources and public services is the effect that international investment agreements may have on national capacities to manage water resources and to regulate public services (see Solanes and Jouravlev, 2007; Bohoslavsky, 2010; Bohoslavsky and Justo, 2011). As a consequence of globalization, many public services are provided and water rights held by companies within foreign investment protection systems or special conflict resolution regimes, which means that external jurisdictions can intervene in local matters. Agreements which over-ride national laws can restrict the power of governments to act in the best public interest and in that of local communities. Many countries have yet to assess the consequences that international investment agreements may have on the economic, social and environmental sustainability and efficiency of water resources utilization and provision of public services.

1.2.4 Equity

Discussions relating to pricing mechanisms and other incentives are predominantly motivated by the objective to enhance efficiency and encourage sustainable water usage at the source of production. Increased efficiency and productivity at a local and national level will be critical in meeting growing global aggregate demands, given mounting pressures on and demand for water resources globally (predominantly through food and agricultural products). Yet it will be important for enhancements in water efficiency and productivity to be accompanied by concomitant efforts to reduce demand. If society operates within ecological limits, and recognizes the limited availability of water resources globally at any one time, it will be unviable for all citizens globally to consume the same amount of water as the highest consuming individuals (and countries) do today. Therefore, efforts to tackle excessive demand in the developed world need to comprise part of a more equitable distribution of the benefits of water globally if increases in demand within emerging economies and developing countries are to be even partially satisfied without heavily depleting aquifers or irreversibly damaging freshwater ecosystems. Although the physical distribution of water across the earth, through the hydrological cycle, is by its nature uneven (see Section 3.1 and Chapter 15), the way in which the goods, products and benefits derived from that water are distributed can be influenced by policy interventions – including global governance frameworks and national water governance arrangements.

In addition to addressing inequities in global demand and consumption, it is also critical to address inequities at the local and national level in terms of the impacts of and benefits derived from the global trade in water resources. Many national or regional water resource management and allocation mechanisms are currently insufficient to sustainably protect resources and equitably distribute any water-derived benefits. The production and export of water-'thirsty' products, such as rice or cotton, in arid areas where water is already under pressure to meet local needs, can exacerbate local and national challenges – including food security. Furthermore, the benefits derived from such production and export are often not experienced by local communities (e.g. through either health care or infrastructure). The virtual water concept has been a useful tool in highlighting the global transport of water through trade; however, new tools will need to be devised to enable the development of sustainable governance mechanisms and policies that rebalance pressures on water resources and seek to equitably distribute any benefits derived from reducing local availability of this precious resource. In this regard, the fact that inequity discriminates against women and children, who make up the largest proportion of the bottom billion, must also be taken into account.

One tool that presents an opportunity to uphold the importance of the equitable distribution of water and its benefits on a national level is the consensus adoption by the United Nations Human Rights Council (HRC) in September 2010 of a resolution affirming that access to water and sanitation is a human right. Building on the July 2010 Resolution[7] by the United Nations General Assembly, recognizing access to safe water and sanitation as a human right, the HRC resolution states that 'the human right to safe drinking water and sanitation is derived from the right to an adequate standard of living and inextricably related to the right to the highest attainable standard of physical and mental health, as well as the right to life and human dignity.'[8] This bestows upon states a certain obligation to promote governance arrangements that secure drinking water supply and sanitation services, and it also provides a basis for further potential discussion and debate on and equitable distribution of social and economic benefits derived from water through agriculture, energy, health and other productive activities. However, these resolutions fail to provide guidance on how progress can be accurately monitored, or how to provide for capital costs – as well as operation and maintenance costs – of the infrastructure (new as well as expanded) required to operationalize them while maintaining affordable prices for the poor.

1.3 Recognizing water in global policy

Recognition of the centrality of water to socio-economic development comes at an opportune time. There are three processes underway to establish global policies that will benefit from this: the MDGs, the UNFCCC and the UNCSD (also referred to commonly as Rio+20).

These three particular processes have been highlighted because of their significant profile and the impact they have at an international level, and because together they cover a number of dimensions relating to global water governance: human health and development, environment and climate change, and broader sustainable development objectives. Importantly, all three processes operate under the auspices of the United Nations,[8] which makes them particularly relevant to this publication. It should be noted, however, that other international forums such as the G8/G20, the World Economic Forum and the World Water Forum can also play an influential role in the recognition of water's central role in socio-economic development, as exemplified by the G8 Water Action Plan (Evian, 2003).

Although these processes can have a significant influence on national policy, their agendas and negotiations are in fact *driven* by the member states. It is therefore up to the different member states themselves to take leadership and ensure that water is put on the agenda of these processes.

1.3.1 Millennium Development Goals

It was appropriate at the turn of the millennium to shine a light on the alarming persistence of poverty in many parts of the world, and on the shameful inequality globally in people's access to basic services. The MDGs helped to emphasize the existence of a right to development, and that the international community has a responsibility to alleviate global suffering. Although many of the MDGs are unfortunately off track, there is no doubt that the framework of clear time-bound goals and targets has been a valuable tool in enabling civil society and the general public to hold governments to account, and that the existence of a relatively short-term 'end-date' has helped to accelerate action in a number of areas.

Yet the MDGs also have their limitations, not least in their failure to recognize the cross-cutting nature of water in relation to all MDGs. For example, it is well-established that improving access to water improves education outcomes (Goal 2) and gender equality and empowerment of women (Goal 3). Water is required to grow food (Goal 1) and improve all aspects of economies to eradicate poverty (Goal 1). These are just a few examples of the positive and cross-sectoral interactions between water and other diverse development imperatives outlined in the MDGs. Energy is another essential, cross-cutting – and water dependent – element of socio-economic development that was overlooked in the MDGs.

One of the targets of the seventh MDG (MDG7), the overall objective of which is to ensure environmental sustainability, is to halve, by 2015, the proportion of the world's population without access to safe drinking water and basic sanitation (Target 7c). However, as currently formulated, it fails to consider essential aspects of service provision, such as their quality, mode of provision or access, and affordability. The world is on track to meet the 'access to safe drinking water' target, although progress varies across regions and sub-Saharan Africa and the Arab Region lag behind. By contrast, the sanitation target (which is not necessarily linked to water, although hygiene is) currently appears out of reach, as half the population of developing regions continue to lack access to basic sanitation.[9]

In light of both progress and continued challenges, it is important that efforts are maintained and intensified to achieve MDG7c by 2015. This poses a real challenge for the international community, especially as the characteristics and criteria related to the requirements to comply with the right to water and sanitation, as recognized by the Human Rights Council, may render the criteria used to set the MDGs obsolete. To date, this community has had no better way to measure and monitor progress than to use the criteria of the MDGs as monitored by WHO/UNICEF's Joint Monitoring Program (JMP) and WHO/UN-Water's Global Analysis and Assessment of Sanitation and Drinking-Water

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(GLAAS), which are based on the concepts of access to *improved* sanitation facilities and drinking water sources. However, new approaches to monitoring these goals are being produced to monitor the goals as now described.

Another limitation of the MDGs is that they neglect the 'centrality of water' to the other goals. While delivery of drinking water and sanitation services should remain a focus of human health and development, the importance of water resources and water governance in achieving the goals collectively needs explicit recognition. It is critical that the drinking water and sanitation issues do not divert attention from the need for efforts to enhance institutional arrangements for water, with water allocation frameworks that prioritize water for these and other basic human needs above all other uses, and which encourage efficiency and productivity in resource use and management. For example, subsidies for irrigation might well be employed to achieve MDG1 to eradicate poverty and hunger, but such policies often discourage efficient water usage and therefore lead to unnecessary levels of extraction, which may ultimately compromise the water source, and in turn the sustainability of both MDG7 and indeed a number of other water-dependent MDGs.

These observations are relevant to water on a number of levels, and the messages from this chapter do have relevance for the way that the MDGs are addressed beyond 2015. First, freshwater is a finite precious natural resource that is essential to all aspects of development. Second, water not only creates connections between the goals, but is also a potential source of conflict between them. In moving beyond 2015, it will be critical to word each of the new goals in such a way as to recognize the role(s) that water plays in achieving them.

1.3.2 The UN Framework Convention on Climate Change

In June 2008, the IPCC Working Group II released a technical paper on water and climate change, which stated that 'the relationship between climate change and freshwater resources is of primary concern to human society and also has implications for all living species' (Bates et al., 2008, p. vii).

Water resources are referred to in Article 4 of the Convention, while at the UNFCCC's 15th Conference of the Parties (COP15) in Copenhagen in 2009, the importance of water resources management for climate change adaptation was referred to in a footnote of the outcome document. Under the UNFCCC, Parties have provided information on freshwater-related impacts and vulnerabilities in their national communications[10] and national adaptation programmes of action (or NAPAs),[11] in which they also spell out adaptation and development priorities.

The newly created institutions in the Cancun Agreements, particularly the Cancun Adaptation Framework and the Adaptation Committee, will provide new and increased opportunities to address the issues around water. At the 16th session of the Conference of the Parties (COP16) in Cancun, 2010, Parties agreed to establish the Cancun Adaptation Framework,[12] with the objective of enhancing action on adaptation, including through international cooperation and coherent consideration of matters relating to adaptation under the Convention. The Cancun Agreement makes specific reference to water resources, freshwater, marine ecosystems and coastal zones when it refers to 'Planning, prioritizing and implementing adaptation actions, including projects and programmes'.[13]

As part of the Cancun Adaptation Framework, developing countries will have the opportunity to address water issues in their National Adaptation Plan, which will provide the opportunity to identify targeted actions. In addition, water and related extreme events like droughts and floods will be considered in the agreed activities under the loss and damage work programme.[14] It is urgent for the member states (i.e. 'Parties') to ensure that water be addressed as a key issue on the agenda for upcoming negotiations.

In a unique move water was tabled for discussion on provisional agenda for the Subsidiary Body for Scientific and Technological Advice (SBSTA) at its 34th session in June 2011, which requested the Secretariat prepare, before its 35th session, a technical paper on water and climate change impacts and adaptation strategies. It was eventually agreed that water would be addressed under the auspices of the Nairobi Work Programme on impacts, vulnerability and adaptation to climate change (the NWP), the work programme with an objective to assist all Parties, in particular developing countries, including the least developed countries (LDCs) and small island developing states (SIDS), to improve their understanding and assessment of impacts, vulnerability and adaptation to climate change, and to make informed decisions on practical adaptation actions and measures to respond to climate change on a sound scientific, technical and socio-economic basis, taking into account current and future climate change and variability. Although not developed to exclusively target specific vulnerable sectors, knowledge products, such as the adaptation practices interface[15] and the local coping strategies database,[16] provide information on adaptation planning and practices on vulnerable sectors at various levels of implementation.

Several partner organizations have pledged actions to undertake research and assessment; enhance technical and institutional capacities; promote awareness; and implement adaptive actions on the ground. These actions have contributed to the enhancement of understanding and assessment of vulnerabilities and adaptation practices related to water resources management. Relevant documents prepared under the NWP to date on water include a synthesis publication on climate change and freshwater resources UNFCCC, 2011) and a technical paper on water and climate change impacts and adaptation strategies.[17]

The mandate for the NWP represents an important building block in mainstreaming and integrating water more effectively in the decision-making of the Convention. Limiting a discussion on water under the UNFCCC to a programme on adaptation means that the cross-cutting and multifaceted nature of the resource will be hard to fully capture unless a congregate of Parties steps forward and assumes a leadership position in recognizing the need to address the multiple and cross-cutting elements of water more comprehensively.

It will also be important to address water in relation to other emerging and important entities of the Convention, including the Adaptation Committee and the Green Climate Fund (GCF). One of the functions of the Adaptation Committee is to provide technical support and guidance to the Parties. Such technical support and guidance should arguably include the provision of expertise in relation to water and adaptation.

The UNFCCC remains to this day one of the most significant global conventions addressing sustainable development. Despite the multitude of valuable multilateral environmental agreements (MEAs), the UNFCCC has captured the imagination and buy-in of international policy-makers and the general public alike more than any other process on environment or sustainable development in the past decade. In this context, ensuring a strong focus on water under the UNFCCC is likely to remain a high priority for the water community.

1.3.3 Beyond the UN Conference on Sustainable Development

The UNCSD 2012, or Rio+20, will take place in Rio de Janeiro 20 years after the first Rio Earth Summit in 1992. The Rio Summit succeeded in putting sustainable water management on the global agenda with Chapter 18 of Agenda 21 (the outcome document from the Summit) dedicated to the 'protection of the quality and supply of freshwater resources'. This chapter represented a significant milestone in the promotion of integrated approaches to water management; that is, managing water across its multiple users.[18] The World Summit on Sustainable Development (WSSD) in 2002 agreed on a specific target for integrated water resources management (IWRM), a concept that by then had become an established part of global water discourse. The target (Article 26) included a call, at all levels, 'to develop IWRM and water efficiency plans by 2005 with support to developing countries'. IWRM is a holistic water management framework that recognizes the multiple users of water – including ecosystems – and so the WSSD's call to plan for it represented a significant step in the right direction. Although its existence has led to a number of national-level initiatives and monitoring processes, progress is far short of the ambitions of the 2005 target and the principle it was trying to push forward. In countries where national plans have been developed, many are not being implemented. Moreover, these plans were meant to be adaptive – in other words, to be part of an ongoing process and thus adaptable to changing conditions and new uncertainties.

In 2006, a task force on water resources management was established under UN-Water, which in its review for the 13th session of the Commission on Sustainable Development in 2008 found that only 6 out of 27 developed countries surveyed had fully implemented IWRM plans, and that only 38% of the developing countries surveyed had plans completed or under implementation. At the request of the UN Commission on Sustainable Development, UN-Water conducted a similar global survey in 2011 to determine progress towards sustainable management of water resources using integrated approaches for the Rio+20 conference. Preliminary findings from the analysis of data from over 125 countries show that there has been widespread adoption of integrated approaches with significant impact on development and water management practices at the country level. The survey showed that 64% of countries have developed IWRM plans, as called for in the Johannesburg Plan of Implementation (JPoI), and 34% report an advanced stage of implementation. However, progress appears to have slowed in low and medium Human Development Index (HDI) countries since the survey in 2008.

Though debate and dialogue on the appropriateness of these and other such specific targets will continue beyond the Rio+20 Summit in June 2012, the consistent messages emerging on water will help to focus and mobilize the water community and hopefully other stakeholders and ensure that water emerges as a priority issue in the global discourse on sustainable development. However, defining and monitoring targets is a difficult exercise, especially given water's centrality, its cross-cutting nature and its wide range of roles and benefits. It may be appropriate for the water community to work with member states, NGOs, various UN agencies and other stakeholders to provide a set of principles recognizing water's central role in achieving various developmental goals. Furthermore, without institutional arrangements for the equitable optimization of water's many benefits in the face of increasing uncertainty, funding for water infrastructure (including operation and maintenance), improved capacity to manage water resources in an integrated and adaptive fashion, most development goals and the 'green economy' itself will continue to be significantly compromised.

UN-Water, following consultations with its members and partners, produced a statement, reflecting the collective opinion of its members on the green economy, as input into the Rio+20 Summit. The statement comprises UN-Water's recommendation to the participants of the Summit as well as a list of potential actions in support of green economic approaches. The main messages of the statement are in Box 1.3.

BOX 1.3

UN-Water's recommendation to UNCSD and potential actions in support of green economic approaches

1. Success of green economy depends on sustainable management of water resources and on safe and sustainable provisioning of water supply and adequate sanitation services. This approach must be underpinned by timely measurement of economic performance in terms of indicators of social and environmental sustainability.
2. The integrated approach to water resources management, as defined in Agenda 21, remains relevant and must be central in strategies towards a green economy.
3. The highest priority must be given to the 'bottom billion' people while addressing inequities in access to water, which are closely linked to energy security as well as food security.
4. Effective management of water variability, ecosystem changes and the resulting impacts on livelihoods in a changing climate scenario are central to a climate-resilient and robust green economy.
5. Universal coverage of water supply and sanitation services must be a central development goal in the post-2015 period. UN-Water urges national governments to set realistic intermediate targets and goals.
6. There must also be a commitment to build the foundation for a water resource efficient green economy.
7. There is a need for increased water resilience and sustainability of cities, keeping in view the global challenges and urbanization trends.
8. Water challenges are a global concern and international action and cooperation at all level are required to accommodate them within the green economy.
9. Green economies can only be achieved if they are supported by green societies.

Source: Water in a Green Economy: A Statement by UN-Water for the UN Conference on Sustainable Development (UNCSD) 2012 (Rio+20 Summit), November 2011.

Conclusion

This chapter has sought to explore the cross-sectoral and global dimensions of water – looking beyond the boundaries of traditional water governance. The mounting demand for water from a diverse range of social and economic sectors, and the potentially irreversible ecosystem impacts of unregulated demand, require strong water governance institutions that facilitate discussion and decisions on the targets of society and the allocation of water resources across sectors to meet them. Equally, water governance frameworks at local, national and regional levels must be complemented by global governance processes, frameworks and institutions that can appropriately address the global dimensions of the benefits of water resources beyond the basin. Water has long ceased to be solely a local issue. Not only do many river basins and aquifers transcend national boundaries, water has also been globalized through international trade in water-dependent products and international investment protection agreements, as well as through climate change impacts on the hydrological cycle, which stand to have potentially devastating affects in certain locations. In a world of increasing uncertainty regarding the demand for finite water resources, global water use will also have to be considered through the lens of equity. Efficiency and productivity gains alone cannot alter global patterns of unequal supply of resources and consumption or access to benefits. Addressing these cross-sectoral and global dimensions of water will require that all countries take an interest in the global forums designed to address and create solutions to impending resource challenges. The water community, and water managers in particular, have the responsibility of informing the process. Implementing the outcomes from global policy agreements will remain a national imperative, but setting the framework requires a widening of the sectoral and spatial horizons of all those who have a stake in water management. Global policy agreements made with local and national processes and reflecting the political economy and institutional capacities of the countries will assure the overall effectiveness of these policies at national and subnational levels.

Notes

1 At the time of preparing the final draft of the WWDR4, the specific post-UNCSD 2012 process was undetermined.

2 The concept of environmental flows recognizes that ecosystems, too, are water users, and that to function properly and provide the necessary services they must benefit from water allocation of sufficient quantity and quality (see eFlowNet, n.d.).

3 For information on the Green Climate Fund see http://unfccc.int/5869.php

4 For more information see http://www.nilebasin.org/newsite/

5 The ISARM2010 International Conference 'Transboundary Aquifers: Challenges and new directions', which took place in Paris, 6–8 December 2010. See http://www.isarm.net/publications/360

6 For the purposes of the WWDR4, 'land acquisition' is defined as the gaining of tenure rights to large areas of land through purchase, lease, concession or other means.

7 Resolution 64/292, 28 July 2010.

8 Human Rights Council, Promotion and protection of all human rights, civil political, economic, social and cultural rights including the right to development, p. 15. Human Rights and Access to Water and Sanitation, 24 September 2010.

9 For further analysis of progress see UN (2010, pp. 58–60).

10 For more information see http://unfccc.int/ 1095.php and http://unfccc.int/2716.php

11 For more information see http://unfccc.int/cooperation_support/least_developed_countries_portal/items/4751.php

12 FCCC/CP/2010/7/Add.1.

13 From page 5 of the report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010, available at http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf

14 For more information see http://unfccc.int/ 6056.php

15 The adaptation practices interface is available at http://unfccc.int/4555.php

16 The local coping strategies database is available at http://maindb.unfccc.int/public/adaptation.

17 See http://unfccc.int/documentation/documents/advanced_search/items/3594.php?rec=j&priref=600006592#beg

18 The United Nations Conference on Environment and Development, Agenda 21, UN, 1992.

References

Arthurton, R., Barker, S., Rast, W. and Huber, M. 2007. Water. *Global Environment Outlook 4*. Nairobi, UNEP, pp. 115–56.

Bates, B. C., Kundzewicz, Z. W., Wu, S. and Palutikof, J. P. (eds). 2008. *Climate Change and Water.* Technical Paper of the Intergovernmental Panel on Climate Change (IPCC). Geneva, IPCC.

Bohoslavsky, J. P. 2010. *Tratados de protección de las inversiones e implicaciones para la formulación de políticas públicas (especial referencia a los servicios de agua potable y saneamiento).* LC/W.326. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/4/40484/Lcw326e.pdf

Bohoslavsky, J. P. and Justo, J. B. 2011. *Protección del derecho humano al agua y arbitrajes de inversión.* LC/W.375. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/2/42342/Lcw0375e.pdf

Bouwer, L. M. 2011. Have disaster losses increased due to anthropogenic climate change? *American Meteorological Society,* Vol, 92, No. 6, pp. 39–46.

Comprehensive Assessment of Water Management in Agriculture. 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture.* London/Colombo, Earthscan/International Water Management Institute (IWMI).

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D. and Savelli, H. (eds). 2010. *Sick Water? The Central Role of Wastewater Management in Sustainable Development. A Rapid Response Assessment.* The Hague, UN-Habitat/UNEP/GRID-Arendal.

De Stefano, L., Duncan, J., Dinar, S., Stahl, K. and Wolf, A. 2010. *Mapping the Resilience of International River Basins to Future Climate Change-induced Water Variability.* World Bank Water Sector Board Discussion Paper Series 15. Washington DC, The World Bank.

eFlowNet (Global Environmental Flows Network). n.d. Website. http://www.eflownet.org/viewinfo.cfm?linkcategoryid=4&siteid=1&FuseAction=display (Accessed 10 May 2011.)

EU (Council of the European Union). 2007. Energy efficiency and renewable energies. *Presidency Conclusions of the Brussels European Council (8/9 March 2007)*. Brussels, EU, pp. 20–22.

Evian. 2003. *Water – A G8 Action Plan.* Document presented at the 2003 Evian Summit, 1–3 June, 2003, Evian-les-Bains, France. http://www.g8.fr/evian/english/navigation/2003_g8_summit/summit_documents/water_-_a_g8_action_plan.html

FAO (Food and Agriculture Organization of the United Nations). 1984. *Systematic Index of International Water Resources by Treaties, Declarations, Acts and Cases, by Basin. Vol. II, Legis. Study No. 34.* http://faolex.fao.org/watertreaties/index.htm

––––. n.d. Women and Population Division. Web page. http://www.fao.org/sd/fsdirect/fbdirect/FSP001.htm

Garrido-Lecca, H. 2010. *Inversión en agua y saneamiento como respuesta a la exclusión en el Perú: gestación, puesta en marcha y lecciones del Programa Agua para Todos (PAPT).* LC/W.313. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/4/41044/lcw313e.pdf

Garrido-Lecca, H. 2011. Design and implementation of and lessons learned from the Water for All Programme. *Circular of the Network for Cooperation in Integrated Water Resource Management for Sustainable Development in Latin America and the Caribbean,* No. 33. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/drni/noticias/circulares/2/42122/Carta33in.pdf

Hamilton, L. S. 2008. *Forests and Water.* A thematic study prepared in the framework of the Global Forest Resources Assessment. Rome, FAO. ftp://ftp.fao.org/docrep/fao/011/.../i0410e01.pdf

Hoekstra, A. Y. 2011. The global dimension of water governance: Why the river basin approach is no longer sufficient and why cooperative action at global level is needed. *Water,* Vol. 3, No. 1, pp. 21–46. http://www.mdpi.com/2073-4441/3/1/21/

Hoekstra, A. Y. and Mekonnen, M. M. 2011. *Global Water Scarcity: Monthly Blue Water Footprint Compared to Blue Water Availability for the World's Major River Basins.* Value of Water Research Report Series No. 53, Delft, The Netherlands, UNESCO-IHE. http://www.waterfootprint.org/Reports/Report53-GlobalBlueWaterScarcity.pdf

Hoffman, A. R. 2011. *The Connection: Water Supply and Energy Reserves.* Washington DC, US Department of Energy. http://waterindustry.org/Water-Facts/world-water-6.htm (Accessed 10 May 2011.)

IEA (International Energy Agency). 2009. *World Energy Outlook 2009.* Paris, IEA.

––––. 2010*a*. *Renewable Energy Essentials: Hydropower.* Paris, IEA. http://www.iea.org/papers/2010/Hydropower_Essentials.pdf

––––. 2010*b*. *World Energy Outlook 2010.* Paris, IEA.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Fourth Assessment Report.* Geneva, IPCC.

ISARM (International Shared Aquifer Resources Management). 2009. *Transboundary Aquifers of the World* (2009 update). Presented during a special meeting at World Water Forum 5. Utrecht, The Netherlands, ISARM. http://www.isarm.net/publications/319#

MA (Millennium Ecosystem Assessment). 2005. *Ecosystems and Human Well-Being: Synthesis.* Washington DC, World Resources Institute.

Mekonnen, M. M. and Hoekstra, A. Y. 2011. *National Water Footprint Accounts: The Green, Blue and Grey Water Footprint of Production and Consumption.* Value of Water Research Report Series No. 50. UNESCO-IHE, Delft, Netherlands. http://www.waterfootprint.org/Reports/Report50-NationalWaterFootprints-Vol1.pdf

Molle, F. and Vallée, D. 2009. Managing competition for water and the pressure on ecosystems. *United Nations World Water Development Report 3: Water in a Changing World.* Paris/London, UNESCO Publishing/Earthscan, pp. 150–9.

OSU (Oregon State University). n.d. TFDD: Transboundary Freshwater Dispute Database. Corvallis, Oreg., Department of Geosciences, Oregon State University. http://www.transboundarywaters.orst.edu

Puri, S. and Aureli, A. (eds.) 2009. *Atlas of Transboundary Aquifers – Global Maps, Regional Cooperation and Local Inventories.* Paris, UNESCO-IHP ISARM Programme, UNESCO. [CD only.] http://www.isarm.org/publications/322

Solanes, M. and Jouravlev, A. 2007. *Revisiting Privatization, Foreign Investment, International Arbitration, and Water.* LC/L.2827-P. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.eclac.cl/publicaciones/xml/0/32120/lcl2827e.pdf

Steer, A. 2010. *From the Pump Room to the Board Room: Water's Central Role in Climate Change Adaptation.* Washington DC, The World Bank. http://www.d4wcc.org.mx/images/documentos/Presentaciones/andrew_steer_keynote_presentation_water_event_december_2_final.pdf

Stern, N. 2007. How climate change will affect people around the world. *The Economics of Climate Change: The Stern Review.* Cambridge, UK, Cambridge University Press, pp. 65–103.

UN (United Nations). 2009. *United Nations Framework Convention on Climate Change (UNFCCC) Copenhagen Accord.* UN Conference of the Parties.

––––. 2010. *The Millennium Development Goals Report.* New York, UN. http://www.un.org/millenniumgoals/pdf/MDG%20Report%202010%20En%20r15%20-low%20res%2020100615%20-.pdf#page=60

––––. 2011. *United Nations Secretary General Report to the 66th General Assembly on the Implementation of the International Strategy for Disaster Reduction.* New York, UN.

UNEP (United Nations Environment Programme). 2011. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication.* Nairobi, UNEP. http://www.unep.org/GreenEconomy/Portals/93/documents/Full_GER_screen.pdf

UNFCCC (United Nations Framework Convention on Climate Change (UNFCCC). 2011. *Climate Change and Freshwater Resources.* A Synthesis of Adaptation Actions Undertaken by Nairobi Work Programme Partner Organizations. Bonn, Germany, UNFCCC. http://unfccc.int/4628.php

UN-Water. 2008. *Transboundary Waters: Sharing Benefits, Sharing Responsibilities.* Thematic paper. Zaragoza, Spain, UN-Water/International Decade for Action (UN-IDfA).

USAID. 2001. *USAID Global Environment Center Environment Notes, The Water-Energy Nexus: Opportunities for Integrated Environmental Management.* Washington DC, USAID.

WEF (World Economic Forum). 2011. *Water Security: The Water-Food-Energy-Climate Nexus.* Washington DC, Island Press.

World Bank. 2004. *Natural Disasters: Counting the Costs.* Washington DC, The World Bank.

––––. 2010. *The Economics of Adaptation to Climate Change: Synthesis Report.* Washington DC, The World Bank.

WWAP (World Water Assessment Programme). 2009. *United Nations World Water Development Report 3: Water in a Changing World.* Paris/London, UNESCO Publishing/Earthscan.

WWC (World Water Council). 2000. *World Water Vision – Results of the Gender Mainstreaming Process: A Way Forward.* Marseilles, WWC.

PART 1

Status, trends and challenges

CHAPTER 2

Water demand: What drives consumption?

Authors David Coates, Richard Connor, Liza Leclerc, Walter Rast, Kristin Schumann and Michael Webber

Human demands for water are usually broken down into five major water use sectors:

- Food and agriculture, which accounts for the majority of water withdrawals globally;
- Energy, for which the quantities of water used (consumptively and non-consumptively) are rarely reported and thus are poorly known;
- Industry, which covers an exceptionally broad range of income-generating activities with equally broad impacts on both the quantity and the quality of local water resources and the environment;
- Human settlements, which includes water for drinking and household uses such as cooking, cleaning, hygiene and some aspects of sanitation;[1] and
- Ecosystems, whose water demands are determined by the water requirements to sustain or restore the benefits for people (services) that societies want ecosystems to supply.

Water managers and decision-makers concerned with meeting humans' basic water-related needs are faced with some important questions: How much water are we using now? How efficiently are we using it? How much will we need 30 years from now? Fifty years? Although these questions appear simple, getting the answers right is not as straightforward as it might seem.

Each of the water use sectors is driven by a number of external forces (such as demographic changes, technological developments, economic growth and prosperity, changing diets, and social and cultural values) which in turn dictate their current and future demands for water. Unfortunately, predicting how these drivers will evolve over the next few decades – and how they will ultimately affect water demand – is fraught with a multiplicity of uncertainties. Future water demands will depend not only on the amount of food, energy, industrial activity, and rural and urban water-related services we will need to meet the requirements of growing populations and changing socio-economic landscapes, but also on how efficiently we can use limited water supplies in meeting these needs.

This chapter draws principally from the Part 3/Volume 2 challenge area reports 'Managing water along the livestock value chain' (Chapter 18), 'The global nexus of energy and water' (Chapter 19), 'Freshwater for industry' (Chapter 20), 'Human settlements' (Chapter 17) and 'Ecosystems' (Chapter 21) to highlight the current challenges and trends specific to each sector, the main drivers and their related uncertainties and risks, and potential response options. With the exception of Section 2.1 (Food and Agriculture) for which all content has been extracted from the respective challenge area report. Sections of this chapter also include complementary material that is not part of the final Part 3 chapters, which were subject to strict length limitations.

2.1 Food and agriculture

The link between water and food is a simple one. Crops and livestock need water to grow, and lots of it. Agriculture accounts for 70% of all water withdrawn by the agricultural, municipal and industrial (including energy) sectors.

Water is the key to food security. Globally, there is enough water available for our future needs, but this world picture hides large areas of absolute water scarcity which affects billions of people, many of whom are poor and disadvantaged. Major changes in policy and management, across the entire agricultural production chain, are needed to ensure best use of available water resources in meeting growing demands for food and other agricultural products.

2.1.1 Water use in agriculture

The agricultural sector as a whole has a large water footprint when compared to other sectors, particularly during the production phase. The booming demand for livestock products in particular is increasing the demand for water, not just during production, but also at every stage along the livestock value chains. It is also affecting water quality, which in turn reduces availability.

The annual global agricultural water consumption includes crop water consumption for food, fibre and feed production (transpiration), plus evaporation losses from the soil and from open water associated with agriculture, such as rice fields, irrigation canals and reservoirs. Only about 20% of the total 7,130 km^3 of agriculture's annual water consumption is 'blue water' – that is, water from rivers, streams, lakes and groundwater for irrigation purposes. Although irrigation is only a modest part of agricultural water consumption, it plays a crucial role, accounting for more than 40% of the world's production on less than 20% of the cultivated land.

Concerns about food insecurity are growing across the globe, but people generally have little or no appreciation of the dependency of food production on water. There is little recognition that 70% of the world's freshwater withdrawals are already committed to irrigated agriculture (Figure 2.1) and that more water will be needed in order to meet increasing demands for food and energy (biofuels). Relatively speaking, withdrawals for agriculture tend to decrease with increasing levels of development.

However, in many countries, not just in the least developed countries (LDCs), water availability for agriculture is already limited and uncertain, and this is set to worsen. Agricultural water withdrawal accounts for 44% of total water withdrawal in OECD countries, but this rises to more than 60% within the eight OECD countries that rely heavily on irrigated agriculture. In the BRIC countries (Brazil, Russian Federation, India and China),[2] agriculture accounts for 74% of water withdrawals, but this ranges from a low 20% in the Russian Federation to 87% in India. In LDCs the figure is more than 90% (FAO, 2011*c*).

Globally, irrigated crop yields are about 2.7 times those of rainfed farming, hence irrigation will continue to play an important role in food production. The area equipped for irrigation increased from 170 million ha in 1970 to 304 million ha in 2008. There is still potential for expansion, particularly in sub-Saharan Africa and Southern America, in places where there is sufficient water available. Pathways to improve productivity and bridge the yield gap in irrigation include increasing the quantity, reliability and timing of water services; increasing the beneficial use of water withdrawn for irrigation; and increasing agronomic or economic productivity so that more output is obtained per unit of water consumed (FAO, 2011*a*).

Although there is still potential to increase the cropped area, some 5–7 million ha (0.6%) of farmland are lost annually because of accelerating land degradation (see Section 4.5 and Chapter 28), and urbanization (see Section 2.4 and Chapter 17), which takes agricultural land out of production and reduces the number of farms as more people move to the cities. Increasing population means that the amount of cultivated land per person is also declining sharply: from 0.4 ha in 1961 to 0.2 ha in 2005.

2.1.2 Expected growth in demand

The world population is predicted to grow from 6.9 billion in 2010 to 8.3 billion in 2030 and 9.1 billion in 2050 (UNDESA, 2009). By 2030, food demand is predicted to increase by 50% (70% by 2050) (Bruinsma, 2009), while energy demand from hydropower and other renewable energy resources will rise by 60% (WWAP, 2009) (see Section 2.2 and Chapter 19). These issues are interconnected – increasing agricultural output, for example, will substantially increase both water and energy consumption, leading to increased competition for water between the different water-using sectors.

Predicting future water demand for agriculture is fraught with uncertainty. It is partially influenced by demand for food, which in turn depends partly on the number of people needing to be fed, and partly on what and how much they eat. This is complicated by, among other factors, uncertainties in seasonal climatic variations, efficiency of agriculture production processes, crop types and yields.

Although projections vary considerably, based on different scenario assumptions and methodologies, future global agricultural water consumption (including both rainfed and irrigated agriculture) is estimated to increase by about 19% to 8,515 km^3 per year in 2050 (Comprehensive Assessment of Water Management in Agriculture, 2007). The Food and Agriculture Organization of the United Nations (FAO) estimates an 11% increase in irrigation water consumption from 2008 to 2050. This is expected to increase by about 5% the present water withdrawal for irrigation of 2,740 km^3. Although this seems a modest increase, much of it will occur in regions already suffering from water scarcity (FAO, 2011*a*).

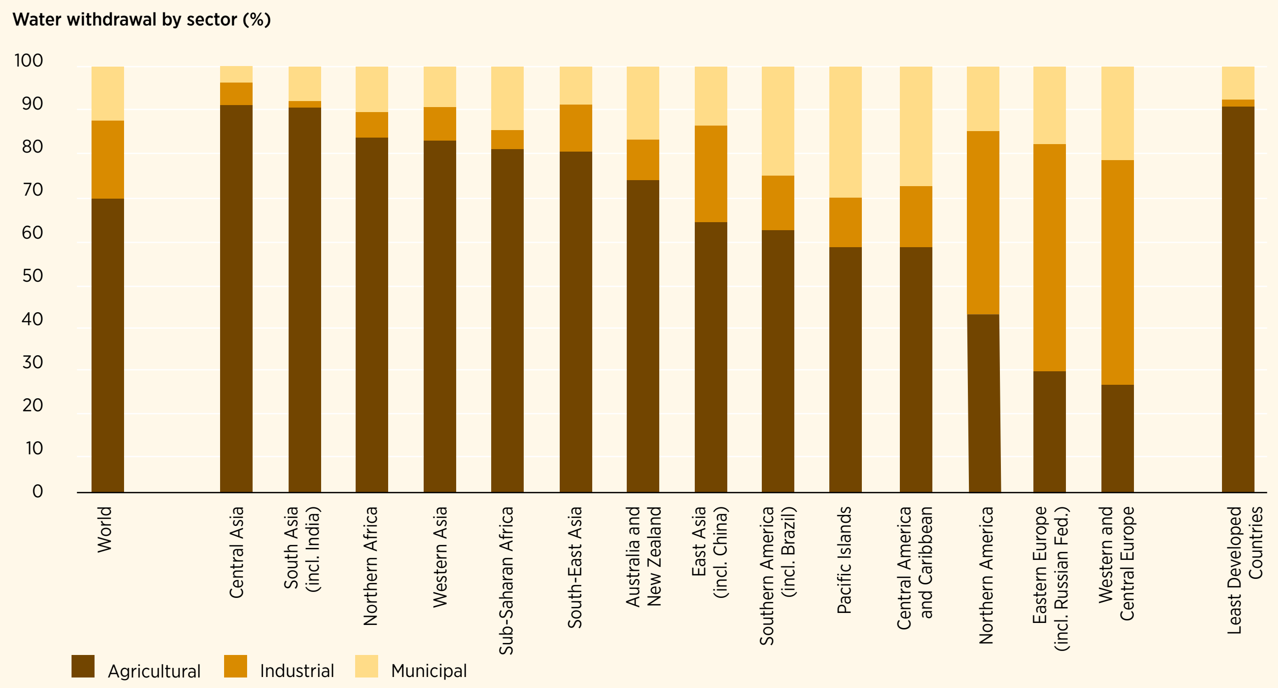
In essence, the main challenge facing the agricultural sector is not so much growing 70% more food in 40 years, but making 70% more food available on the plate. Reducing losses in storage and along the value chain may go a long way towards offsetting the need for more production.

2.1.3 Agriculture's impacts on water and ecosystems

The way that water is managed in agriculture has caused wide-scale changes in ecosystems and undermined the provision of a wide range of ecosystem services. Water management for agriculture has changed the physical and chemical characteristics of freshwater and coastal wetlands and the quality and quantity of water, as well as direct and indirect biological changes in terrestrial ecosystems. The external cost of the damage to people and ecosystems, and clean-up processes, from the agricultural sector is significant. In the United States of America (USA), for instance, the estimated cost is US$9–20 billion per year (cited in Galloway et al., 2007).

FIGURE 2.1

Water withdrawal by sector by region (2005)



Source: FAO AQUASTAT (http://www.fao.org/nr/water/aquastat/main/index.stm, accessed in 2011).

Land-use changes as a result of agriculture have produced a wide range of impacts on water quantity and quality (Scanlon et al., 2007). Wetlands in particular have been affected. Poor water quality originating from agricultural pollution is most severe in wetlands in Europe, Latin America and Asia (Figure 2.2). The status of species in freshwater and coastal wetlands has been deteriorating faster than those of other ecosystems (MA, 2005*a*).

Diffuse pollution from agricultural land continues to be of critical concern throughout many of the world's river basins (see Sections 3.3 and 4.3). Eutrophication from agricultural runoff ranks among the top pollution problems in Canada, the USA, and Asia and the Pacific. Australia, India, Pakistan and many parts of the arid Middle East face increasing salinization as a result of poor irrigation practices (MA, 2005).

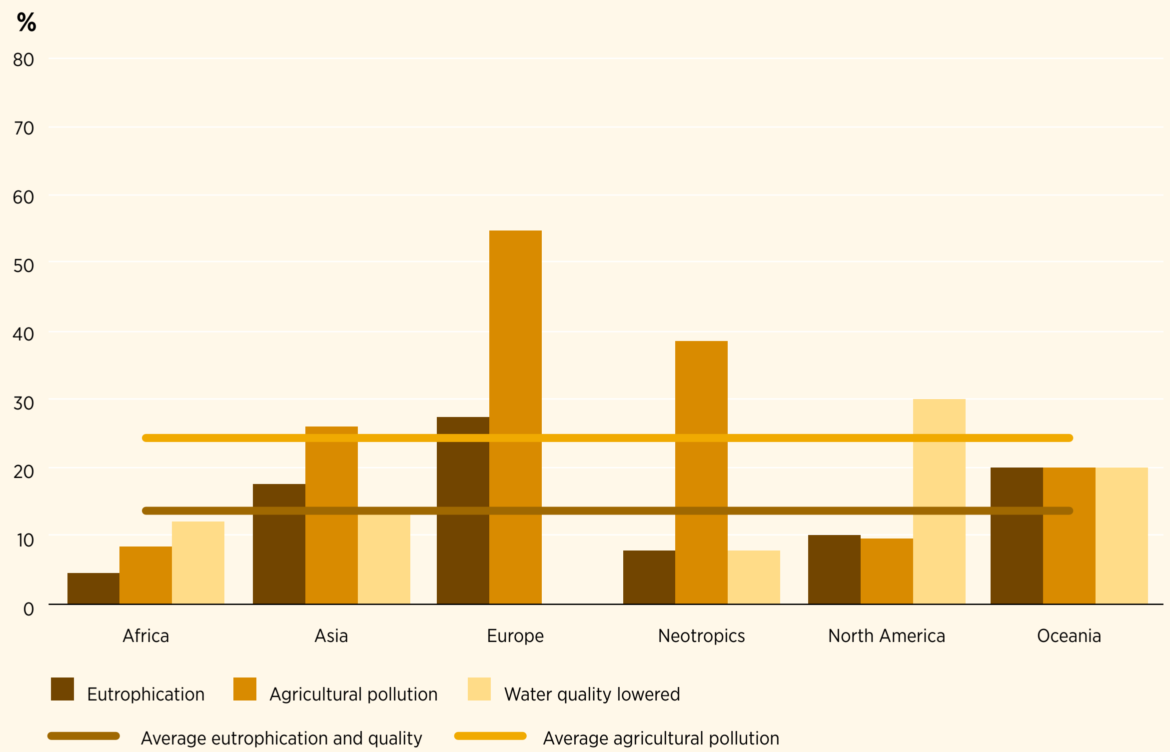
Nitrate is the most common chemical contaminant in the world's groundwater resources. According to available data in FAO AQUASTAT (2011*c*), the USA is currently the country consuming the largest amount of pesticides, followed by countries in Europe, especially those of Western Europe. In terms of use per unit area of cultivated area, Japan is the most intensive user of pesticides. Over-abstraction of renewable groundwater resources and abstraction of fossil groundwater reserves in arid North Africa and the Arabian Peninsula, driven primarily by the agricultural sector, are exerting irreconcilable pressures on water resources.

2.1.4 Pressures from population growth and changing diets

The growing population (9.1 billion by 2050, as per above) is increasing the pressures on land and water. At the same time, economic growth and individual wealth are shifting diets from predominantly starch-based to meat and dairy, which require more water. Producing 1 kg rice, for example, requires about 3,500 L water, 1 kg beef some 15,000 L, and a cup of coffee about 140 L (Hoekstra and Chapagain, 2008). This dietary shift is the greatest to impact on water consumption over the past 30 years, and is likely to continue well into the middle of the twenty-first century (FAO, 2006).

FIGURE 2.2

Wetlands water quality state changes by continent



Source: FAO (2008, p. 50).

Demand for livestock products is closely linked to economic growth

The world food economy is being increasingly driven by the shift in diets and food-consumption patterns towards livestock products (FAO, 2006). In 2008, 3,350 million ha were used as permanent meadows and for pasture – more than twice the area used for arable cropping and permanent crops. Livestock provides not just meat, but also dairy products, eggs, wool, hides and so on. The livestock sector is now changing at an unprecedented pace as demand for food derived from animals has boomed in the world's most rapidly growing economies (Steinfeld et al., 2006). Livestock already contributes 40% of the global value of agricultural output. It constitutes one of the most dynamic parts of the agricultural economy, driven by population growth, rising affluence and urbanization.

But the increasing demand for livestock products is being matched by concerns about its impacts on the environment. The expansion of land for livestock has led to deforestation in some countries (e.g. Brazil) and intensive livestock production (mainly in OECD countries) is already a major source of pollution. Livestock contributes less than 2% of global gross domestic product (GDP), yet produces some 18% of greenhouse gases (GHGs) (Steinfeld et al., 2006*b*). Hence critics argue that the dis-benefits from livestock far outweigh the benefits, but others argue that this seriously underestimates the economic and social importance of livestock, particularly in low-income countries. Regardless of the balance of these arguments, the increasing demand for livestock seems likely to continue (FAO, 2006). This means that resource-use efficiency in livestock production is now an urgent priority, and this includes the management of water.

Water pollution from livestock production and processing

During the production phase, livestock requires water for drinking, cooling and cleaning, but the amounts required differ according to the animal, the method of rearing and the location. Extensive livestock systems can increase water demand because of the additional effort required as animals search for feed. Intensive or industrialized systems, however, require additional service water for cooling and cleaning facilities. Globally, the annual drinking water requirement for livestock is about 16 km^3 and services require another 6.5 km^3 (Steinfeld et al., 2006).

The amount of water used to grow feed and fodder is much more significant in volume terms. This amount depends not just on the number and kinds of animals and amount of food they eat, but also where the food is grown. It is estimated that livestock consume about 2,000–3,000 km^3 of water annually – as much as 45% of the global water embedded in food products (Comprehensive Assessment of Water Management in Agriculture, 2007; Zimmer and Renault, n.d.) – although these estimates are quite imprecise. Rainfed grasslands and non-cultivated grazed fodder crops consume most of this water and this is generally thought to be of little environmental value. Indeed, if these lands were not used for grazing there would be very little water saving or potential for alternative use. Irrigation water volumes are much smaller, but play an important role in producing feed, fodder and grazing for livestock, and have a much greater opportunity cost than rainfed cropping.

During meat processing, the slaughterhouse is the second largest user of water in the meat-processing value chain (after the production phase), and a potentially significant point source of pollution to local ecosystems and communities. But the most serious aspect of food consumption is food wastage. This is particularly the case in industrialized countries where food is wasted because too much perishable food is produced and not sold, products deteriorate in storage, and food is bought and not consumed and hence thrown away. All this adds up to both a significant waste of food, and also a significant waste of the water used to produce it (Lundqvist, 2010).

2.1.5 Other pressures on water resources in the agriculture sector

Climate change

Agriculture contributes to climate change through its share of GHG emissions, which in turn affect the planet's water cycle, adding another layer of uncertainties and risks to food production. Climate change impacts are mainly experienced through the water regime, in the form of more severe and frequent droughts and floods, with anticipated effects on the availability of water resources through changes in rainfall distribution, soil moisture, glacier and ice/snow melt, and river and groundwater flows. These climate change-induced hydrological changes are likely to affect both the extent and productivity of irrigated and rainfed agriculture worldwide, hence adaptation strategies will focus on minimizing the overall production risk (FAO, 2011*b*).

> "Food security is threatened by the potential for waste as agricultural products move along extensive value chains and pass through many hands ... from field to fork."

It is predicted that South Asia and Southern Africa are predicted will be the most vulnerable regions to climate change-related food shortages by 2030 (Lobell et al., 2008). Their populations are food-insecure because they are highly dependent on growing crops in ecosystems that display high vulnerability and consequences to climate change projections of temperature and precipitation changes.

Food, economy and the energy crisis

The food price crisis, followed shortly by the 2009 economic crisis, has had tragic consequences for world hunger. Food prices are significantly higher than they were in 2006. Although the factors which led to this increase in food prices were thought to be temporary – such as drought in wheat-producing regions, low food stocks and soaring oil barrel prices that drove up the price of fertilizers – food prices in 2010 had not yet returned to their pre-2006 levels. Poor women shoulder the brunt of economic crises and women with less education tend to increase their work participation more in times of crisis in almost every region of the world (FAO, 2009).

The demand for biofuels has also soared in recent years. Substantial amounts of maize in the USA, wheat and rapeseed in the European Union (EU), oil palm in parts of sub-Saharan Africa and South and South-East Asia, and sugar in Brazil, are being raised for ethanol and biodiesel production. In 2007, biofuel production was dominated by Brazil, the USA, and to a lesser extent, the EU. Biomass and waste represented 10% of the world's primary energy demand in 2005, more than nuclear (6%) and hydro (2%) combined (IEA, 2007).

If a projected bio-energy supply of 6,000–12,000 million tonnes of oil equivalent were to be reached in 2050,[3] this would require one-fifth of the world's agricultural land (IEA, 2006). Biofuels are also water intensive and can add to the strains on local hydrological systems and GHG emissions.

Land acquisitions and land-use changes

The relatively recent phenomenon of large-scale, international land acquisitions is leading to land-use changes, which in turn impacts water use. Since 2007–2008, sovereign funds and investment companies of some OECD and BRICS countries have bought or leased large tracts of farmland across Africa, Asia and Latin America in order to secure their fuel and food requirements. This was triggered in part by the fuel crisis and the demand for biofuels to replace petroleum-based products, as explained in greater detail in Chapter 7 (Box 7.14). The problem is that in most states where such contracts are being completed, water rights are often not codified in 'modern' law, but are based on local traditions, weak and outdated water legislation or non-existent in any formal legal terms (Mann and Smaller, 2010).

2.1.6 Waste in the food chain

When water is scarce it is no longer enough just to consider the amount of water needed to grow food (Lundqvist, Fraiture and Molden, 2008). The way water is used along the entire value chain must be examined, from production to consumption and beyond. This is particularly true for the more industrialized countries, and also to some extent in the towns and cities of BRICS countries, where food increasingly comes from many different sources, often over long distances, and in some cases from many different countries. Food security is threatened by the potential for waste as agricultural products move along extensive value chains and pass through many hands – farmers, transporters, store keepers, food processors, shopkeepers and consumers – as it travels from field to fork. Food can be wasted at every step along the value chain, which means that the water used to produce it is also wasted.

Water management has traditionally been the responsibility of governments, but major international food companies are beginning to realize the importance of water to their businesses, particularly where their value chains are situated in water-short countries. Although their concern may have more to do with customer perceptions and security of profits, using water with greater care can provide potential knock-on benefits for all. Initiatives to promote more efficient use of water along the value chain include, for example, the CEO Water Mandate and the Alliance for Water Stewardship.

2.1.7 'Water-smart' food production

The world is clearly entering a new era of water management characterized by increasing recognition of the links between water and other resources and the socio-economics of poor post-harvest management and food waste along the value chain.

The role of technology

In higher income countries, science and technology have long been major drivers of global prosperity. This will undoubtedly continue in the future. Food production will need to be much 'greener' and more sustainable to ensure that it does not add to the burden of climate change and ecosystem deterioration.

Innovative technologies will be needed that can improve crop yields and drought tolerance; produce smarter ways of using fertilizer and water; improve crop protection through new pesticides and non-chemical approaches; reduce post-harvest losses; and create more sustainable livestock and marine production. Industrialized countries are well placed to take advantage of these technologies, but also have the responsibility to ensure that LDCs have opportunities to access them on equitable or non-discriminatory terms.

Human capacities and institutions are assets

Agricultural development in LDCs lies mainly in the hands of smallholders, a large majority of whom are women. Water technologies appropriate to their needs will play a crucial role in meeting the food security challenge. However, in many LDCs women have only limited access to a wide range of physical assets and lack the skills to deploy them. Multiple water-use schemes can provide opportunities for women to extend their influence over water allocation and management.

Major changes in policy and management will be needed to make best possible use of available water resources. New institutional arrangements are needed that centralize the responsibility for water regulation, yet decentralize water management responsibility and increase user ownership and participation. New arrangements are required for safeguarding access to water for poor and disadvantaged groups, particularly women, and ensuring they have long-term land and water security.

A focus on the value chain

Improvements will be needed all along the agricultural value chains. Early gains include opportunities to reduce post-harvest crop losses in LDCs and food wastage in the higher income countries, hence saving the water embedded in them. In the medium term, innovations in climate-smart cropping are possible. In the longer term, energy-smart conversion of feed and fodder for livestock is also possible. Water recycling at all stages of the value chain can help secure environmental water requirements when reuse of treated water is not culturally acceptable for other uses.

Managing risk creatively

Reducing vulnerability to drought will require investment in both constructed and 'green' infrastructure to improve water measurement and control and, where appropriate, increase surface water and groundwater storage in constructed reservoirs and in natural storage both in wetlands and in the soil. Most benefit is expected to come from existing water management technologies through adaptation to new situations. 'Design for management', promoted in the 1980s to ensure infrastructure design took account of who would manage it and how it would be managed, remains highly relevant today and important for future water management.

Virtual water trade

Virtual water may play an increasing role as water-rich countries export water embedded in food to water-short countries that find it increasingly difficult to grow sufficient staple food crops. But the aqua-politics of exporting/importing food versus self-sufficiency will not be easy to resolve. Food-producing countries may not wish to export crops when food security is threatened; lower income and LDCs may need to continue over-exploiting water resources to feed their populations to avoid market-imposed high prices. Subsidies on food and other products can distort markets with possible negative implications on the use of the virtual water notion.

Implementing 'water smart' production

A twin-track approach is needed that makes best use of available water: demand-management options that

"All forms of energy require water at some stage of their life cycle, which includes production, conversion, distribution and use."

increase productivity (more 'crop per drop') and supply management that makes more water available through water storage to cope with seasonality and increasingly unpredictable rainfall.

Major investment in agricultural water management will be needed and the present-day national priorities in some countries give cause for serious concern. In 2010, it was estimated that only US$10 billion was invested globally in irrigation systems, a surprisingly low figure given the importance of water for the agricultural sector (in comparison, the global market volume for bottled water in the same year was US$59 billion) (Wild et al., 2010). Surely it is time for the world to wake up to the fact that agriculture is a major, valid consumer of water, and that investment is essential for the future of food and water security. When water is scarce there is a global responsibility to use water wisely, efficiently and productively. Agriculture needs to be much more 'water-smart' and must be given the right signals and incentives to make this happen.

2.2 Energy

Energy and water are intricately connected. Although there exist different sources of energy and electricity, all require water for various production processes, including extraction of raw materials, cooling in thermal processes, cleaning materials, cultivation of crops for biofuels, and powering turbines. Conversely, energy is required to make water resources available for human use and consumption through pumping, transportation, treatment, desalination and irrigation. This double-sided interdependency of both resources has been coined the water-energy nexus, and introduces key cross-sectoral vulnerabilities.

The challenge of managing this nexus is increased by external drivers, whose impact can only be estimated but never wholly planned for. Climate change is a central external driver that affects both water and energy directly; mitigation measures are concentrated around the reduction of energy consumption and carbon emissions, while adaptation means planning for increasing hydrological variability and extreme weather events, including floods, droughts and storms. Further external pressures are created through demographic development, both from population increase and migration, as well as from increased economic activity and living standards, which will generate a surge of energy consumption, particularly in non-OECD countries. Lastly, policy choices by governments often exacerbate the strains by pursuing more water-intensive energy and more energy-intensive water.

2.2.1 Water for energy

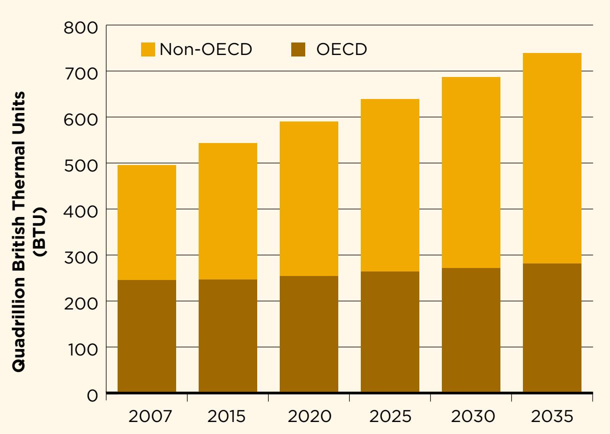
Trends and forecasts in the demand for different types of energy

EIA (2010) estimates that global energy consumption will increase by around 49% from 2007 to 2035 (Figure 2.3). This increase in energy consumption will be higher in non-OECD countries (84%) than in OECD countries (14%), with the primary driver being the expected growth in GDP and the associated increased economic activity.

Energy sources are often divided into primary and secondary energies. Primary energies are extracted, captured or cultivated, and include crude oil, natural

FIGURE 2.3

World marketed energy consumption, 2007–2035



Source: EIA (2010, p. 1).

gas, coal, biomass and geothermal heat. Secondary energies undergo a transformation process into petroleum products and electricity generated from thermal processes (coal, fossil fuels, geothermal, nuclear) and hydropower, solar/photovoltaic (PV) and wind (Øvergaard, 2008).

With regard to primary energy carriers, Figure 2.4 shows that fuel production is expected to increase until 2035. While the increase in crude oil production is expected to be small, significant increases are expected in the production of biofuels, coal and natural gas. In particular, the production of biofuels has significant water impacts because of the water requirements of crops for growth during photosynthesis, along with other water uses at the biorefinery.

Similarly, there are great disparities in the 2035 trends for electricity production. Figure 2.5 shows that no increases can be expected in electricity from liquid fossil fuels, and very little from nuclear production. Notably, the global nuclear policy consequences of the nuclear accident in Fukushima, Japan, in March 2011 might further inhibit future nuclear generation. The production of electricity from coal, renewable energy and natural gas, however, is expected to increase significantly. Electricity production from renewables is expected to more than double until 2035 (Figure 2.4), with hydropower growing in overall production, but less significantly in percentage than wind, solar and PV (EIA, 2010; WWF, 2011).

Water requirements for primary energy

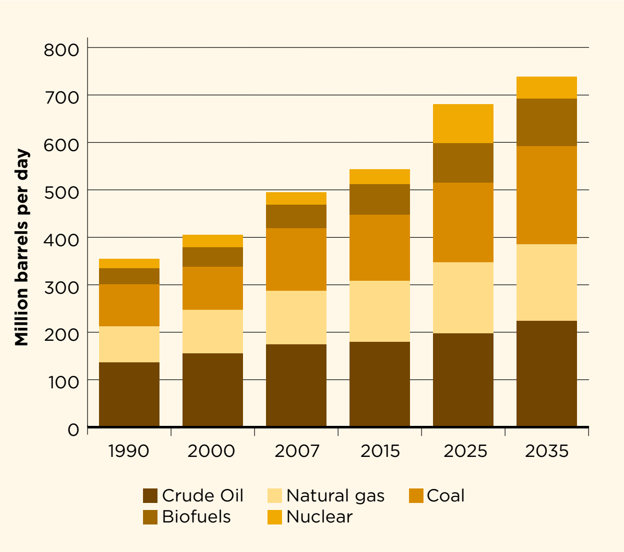
All forms of energy require water at some stage of their life cycle, which includes production, conversion, distribution and use. This chapter focuses on water quantity requirements, instead of water quality impacts. The water requirements for fuel production for coal, natural gas and uranium, while non-trivial, are much smaller than the water requirements at their use within power plants, and are therefore considered negligible by comparison. By contrast, the water requirements to produce coal, natural gas and petroleum for transportation applications are significant by comparison (because transport vehicles have no water requirements on-board.) Each fuel and technology has a slightly different set of requirements.

Crude oil

Crude oil is currently the largest primary energy source globally. Its production requires water at various stages, including drilling, pumping, refinement and treatment. The average water use is estimated to be 1.058 m^3 per GJ (Gerbens-Leenes, et al., 2008). Unconventional oil production, which is projected to increase in North,

FIGURE 2.4

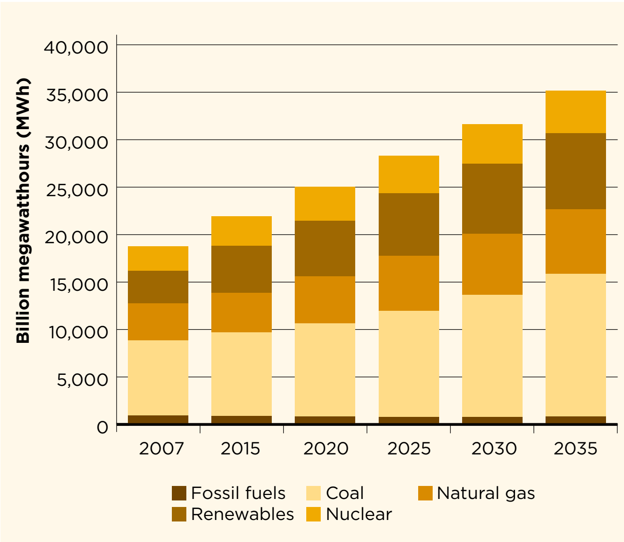
Historical world fuel production from 1990 to 2007 with projections to 2035



Source: Data from EIA (2010).

FIGURE 2.5

Projections for world net electricity generation, 2007–2035



Note: for this figure, fossil fuels refers to liquids such as petroleum and liquefied gases. Coal and natural gas are considered separately.
Source: Data from EIA (2010).

Central and South America until 2035, consumes 2.5 to 4 times more water (WEC, 2010).

Coal

Coal is the second largest primary energy source globally, and its use is projected to increase by 2035 (Figure 2.4). Gerbens-Leenes et al. (2008) estimate that approximately 0.164 m^3 per GJ are used in the various processes, significantly more of which is used during underground mining operations than in open pit mining (Gleick, 1994).

Natural gas

Significant increases are expected in the production of natural gas by 2035 (Figure 2.4). Water requirements for the drilling, extraction and transportation of conventional gas sources are relatively modest, at an estimated 0.109 m^3 per GJ (Gerbens-Leenes et al., 2008). However, shale gas production, which is expected to increase in Asia, Australia and North America (Gascoyne and Aik, 2011), has slightly higher water-intensity than conventional gas, because its extraction method, hydraulic fracturing, injects millions of litres of water into each well.

Uranium

Uranium's share of global energy consumption is projected to increase from about 6% today to 9% by 2035 (Figure 2.4) (WEC, 2010). Gerbens-Leenes et al. (2008) estimate that water requirements for uranium mining and processing are modest at 0.086 m^3 per GJ.

Biomass and biofuel

Biomass, including wood, agro fuel, waste and municipal by-products, is an important source of fire and heating in many non-OECD country households (WEC, 2010). Furthermore, biofeedstocks are increasingly grown commercially to replace the use of fossil fuels in OECD countries – a trend that has raised concerns over the crop water requirements. However, the water intensity depends on the feedstock, where and how the crops are grown, and whether they are first or second-generation crops (Gerbens-Leenes et al., 2008; WEF, 2009). Due to this variety of production processes, it is impractical to attribute a singular value or even a representative range of water consumption to biofuel production.

Water requirements for the generation of electricity

Thermal electricity

Thermal power plants (coal, gas, oil, biomass, geothermal or uranium) generate electricity by heating water or gases and running them through steam or gas turbines to drive electrical generators. After passing through turbines, the water in the steam cycle is generally cooled (via water cooling loops) in a condenser and recycled. These processes currently account for 78% of world electricity production (EIA, 2010) and output is expected to grow, implying that even more water cooling will be needed.

Two types of water-cooling technologies as well as dry cooling are currently used (WEF, 2011). Once-through cooling withdraws relatively large quantities of water that are returned to the water body downstream after passing through the condenser. While some water is lost to evaporation (WEC, 2010), little water is actually consumed. However, significant downstream stresses on aquatic life can occur when the returned water has a significantly higher temperature than the environment, or if aquatic life is entrained into the cooling systems (DOE, 2006). Closed loop systems re-circulate the cooling water in the condenser and eject excess heat through cooling towers or ponds (WEF, 2011). These closed systems withdraw 95% less water than once-through technologies, but all of this water is lost to evaporation such that no water is returned directly to the natural system. Dry cooling systems do not require water for cooling, but have parasitic efficiency losses and have varying performance depending on the local temperature and humidity.

Values for the water consumption of thermal power plants vary due to the variety of existing technologies and fuel sources, as well as the climatic differences, which influence evaporation and the selection of the cooling process.

Hydropower

Hydropower presents the largest renewable source of electricity generation (15% of global production in 2007), and it is estimated that two-thirds of the world's economically feasible potential is still to be exploited (WEC, 2010). Hydropower uses water as its fuel by running it through turbines and discharging it to a water body further downstream. In this process, the water remains unpolluted and the hydropower production process is therefore by definition non-consumptive. However, in the case of storage reservoirs, additional evaporation might occur and has recently come to be considered by some observers as the water consumption of hydropower – even though evaporation losses are not usually factored into other reservoir-related uses. Estimation of water consumption for hydroelectricity is particularly difficult as it relies on modelling rather than measuring (WEF, 2009). Most of the latest research on this topic comes from the USA with findings presenting a range from 0.04 to 210 m^3 per MWh with an expected median of 2.6 to 5.4 m^3 per MWh (Gleick, 1994). Such estimates are meant to reflect losses through evaporation that would exceed what would have occurred if the basin had remained at its normal run-of-river surface area. It is important to note that these losses are not caused by hydropower generation itself, but by the surface area of reservoirs and site-specific climatic conditions, and could thus be applied to any water use that includes a reservoir, man-made or natural. Box 2.1 presents this and some of the complexities that are associated with the consideration of water use and consumption during hydropower production in comparison with other types of energy, and raises several points that are valid to measuring 'losses' attributable not exclusively to hydropower but to reservoirs for different, often multiple uses.

Wind, solar and photovoltaic

Wind and solar PV currently account for 3% of global electricity production. During operation, these technologies use virtually no water with the exception of that for washing of blades or solar cells (WEF, 2009). However, water requirements for washing of solar panels can be important to remove dust when operating in or near deserts. Also, in the case of large-scale deployment of concentrating solar power, the electricity is generated via the same steam cycle as thermal power plants and will therefore have cooling water

BOX 2.1

Complexities in comparing water use and consumption for hydropower production with that for other types of energy

Evaporation from hydroelectric power plants was initially researched in the early 1990s in the United States of America in an attempt to quantify the water usages of several energy resources. While few recent measurements exist, the US figures from the 1990s are frequently used to represent water requirements for hydropower at a global level (Figure 2.5). Pegasys (2011) notes that several points need to be considered when considering the impact of hydropower on the water resource:

- **Understanding water 'use', 'consumption' and 'loss'.** It is important to clarify the concepts and terminology associated with the 'non-consumptive use' of water for hydropower generation. While hydroelectric production does not 'consume' water, there are: (1) losses through evaporation that exceed what would have happened if the basin had remained at its run-of-river surface area, and (2) downstream impacts associated with altered flow regimes that need to be taken into account. Perhaps the most common complication arises with uses that rely on reservoir storage to allocate annual stream flow over time. For example, in many locations, as in Chile, hydroelectricity generation competes with other water uses because it shapes stream flows to meet power demand that are often out of phase with the seasonal requirements for other uses (Huffaker, Whittlesey and Wandschneider, 1993; Bauer, 1998).
- **Nature of generation capacity.** Understanding a generation technology and its footprint outside of the wider national or regional electricity system raises particular difficulties. Each generation facility has a prescribed performance and cost profile that determine its dispatch order and therefore water usage. This role can only be understood in the context of the other sources of power generation. For example hydropower has multiple uses in systems either as baseload capacity, peaking capacity or support. Furthermore, hydropower reservoirs potentially serve multiple purposes, including recreation, navigation, flood control and water storage, hence allocating its impacts across its myriad of services is difficult.
- **Energy supply chain.** Each generation technology has a different supply chain. A consideration of this supply chain from extraction of raw material to final product is critical in understanding the footprint of that technology. An omission of the supply chain obscures the water requirements for the technology and complicates comparisons between technologies.
- **Attribution of losses.** Hydropower in many instances is one of the functions in a multi-objective project, and the attribution of reservoir evapotranspiration to all of the uses is necessary when considering the footprint and usage of hydropower.
- **Structure of the hydropower system.** Each hydropower system is structured differently based on the nature and flow of the river system. Reservoir sizes, depth and shapes, as well as installed capacity, depend on the pre-existing geography, and determine the evaporation as well as generation value, highlighting the need to evaluate each project based on its specifics.
- **Climatic setting.** There is considerable debate around impact (or opportunity cost) of the footprint on the water resources of local basins. The meaning of the same footprint in a basin with excess water is different from that in a water-scarce basin.

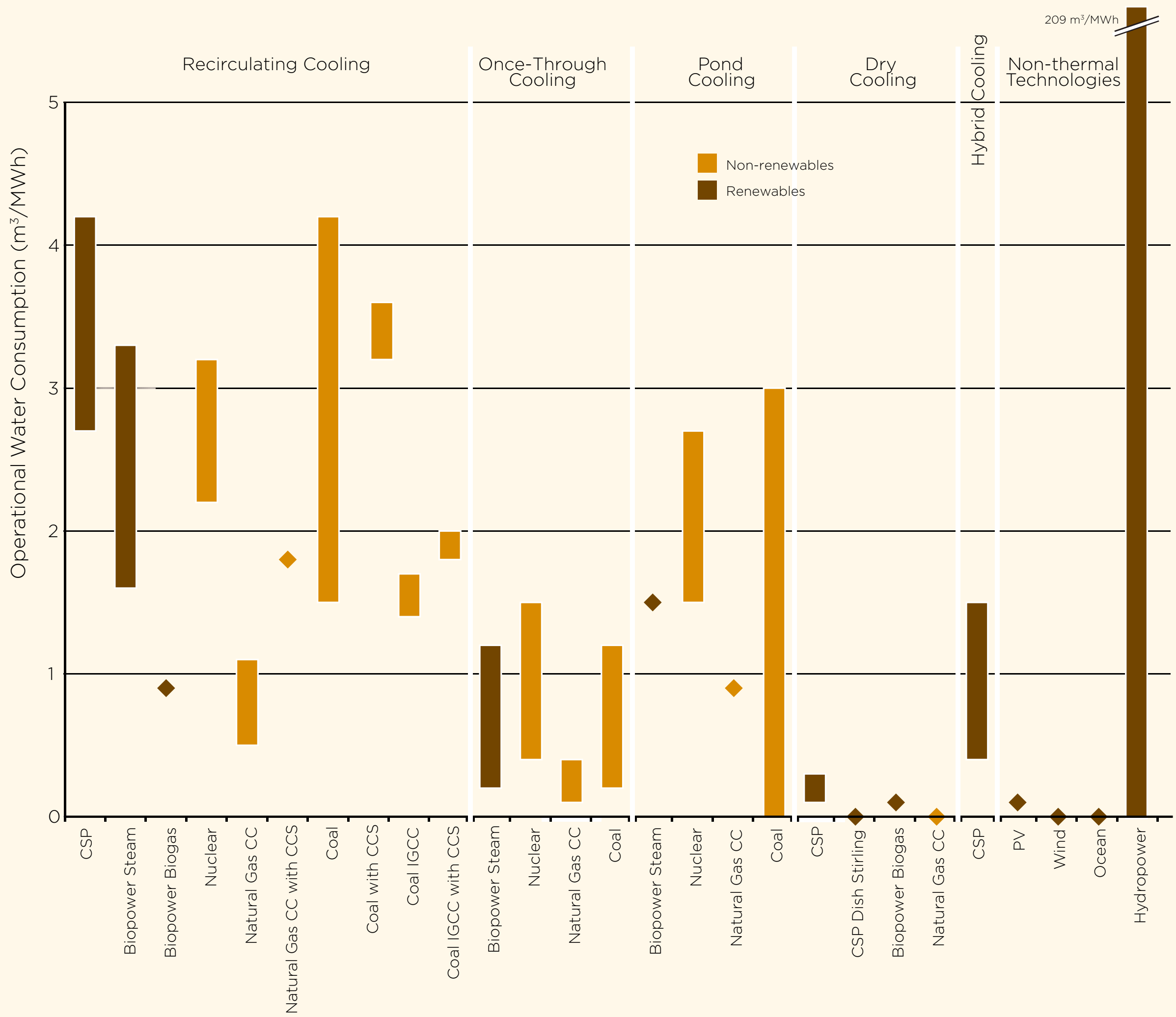
requirements, which can be a challenge in hot and dry regions (Carter and Campbell, 2009).

As a general trend, energy and electricity consumption are likely to increase over the next 25 years in all world regions, with the majority of this increase occurring in non-OECD countries. This trend will have direct implications for the water resources needed to supply this energy. Table 2.1 shows that the anticipated water requirements for energy production will increase by 11.2% by 2050 if current consumption modes are kept. Under a scenario that assumes increasing energy efficiency of consumption modes, WEC (2010) estimates that water requirements for energy production could decrease by 2.9% until 2050 (Table 2.2). Unfortunately, the water availability required for energy production is often not considered when new energy production facilities are planned. Similarly, energy needs for water systems are also often overlooked.

Water resources are not evenly distributed on the planet, and correspondingly some regions will face more severe water-for-energy stresses than others. WEC (2010) estimates that China, India and the Middle East, which already experience water stresses and are forecast to experience a five-fold increase in electricity production, will increasingly need to explore new technologies for processing primary energies and generating electricity. Other regions, although experiencing increasing water requirement for energy production,

FIGURE 2.6

Operational water consumption for the production of various types of energy



Source: IPCC (2011, fig. 9.14, p. 49). Trends in the demand of water for energy will most likely not suffer from water stress or scarcity, as they possess sufficient resources. WEC (2010) estimates that this scenario will be the case for most parts of North and South America and the Caribbean.

2.2.2 Energy for water

Energy is needed for extraction (surface water, groundwater), transformation (treatment to drinking water standards, desalination), water resource delivery (municipal, industrial and agricultural supply), reconditioning (wastewater treatment) and release. However, few countries currently research and report on energy requirements for water.

EPRI (2002) estimates that 2-4% of total US electricity consumption is used for water provision at water and wastewater treatment plants. Including end-uses, the national US energy consumption for water is approximately 10% (Twomey and Webber, 2011). Energy requirements for surface water pumping are generally 30% lower than for groundwater pumping (EPRI, 2002). It can be expected that groundwater will become increasingly energy intensive as water tables fall in several regions. In addition, where surface water is not abundant, importing water into the region might be more energy intensive than pumping available groundwater resources.

Water is commonly cleaned to meet drinking water standards by removing salts and chemical and biological contaminants. The energy requirements used for surface and groundwater treatment vary largely, based on water quality (WEF, 2011), technology used (Strokes and Horvath, 2009) and national drinking water standards. However, in international life-cycle analyses, it has been observed that desalination of locally available sources generally requires significantly more energy than importing water sources (Strokes and Horvath, 2009), and requires generally six times more energy than wastewater treatment (WEF, 2011). Electricity requirements for desalination are relatively well researched, and Strokes and Horvath (2009) found that international electricity use for conventional and membrane seawater desalination treatment averaged 0.38 kWh per year per m^3, while brackish groundwater desalination requires about 0.26 kWh per year per

TABLE 2.1

Population, energy consumption and water consumption for energy, 2005–2050

World	2005	2020	2035	2050
Population (million)	6290	7842.3	8601.1	9439.0
Energy consumption (EJ)	328.7	400.4	464.9	518.8
Energy consumption (GJ/capita)	52.3	51.1	54.1	55
Water for energy (billion m^3/year)	1815.6	1986.4	2087.8	2020.1
Water for energy (m^3/capita)	288.6	253.3	242.7	214.0

Source: Adapted from WEC (2010, table 1, p. 50, various data sources).

TABLE 2.2

Population, energy consumption and water consumption for energy, 2005–2050, with improved energy efficiency

World	2005	2020	2035	2050
Population (million)	6290	7842.3	8601.1	9439.0
Energy consumption (EJ)	328.7	364.7	386.4	435.0
Energy consumption (GJ/capita)	52.3	46.5	44.9	46.1
Water for energy (billion m^3/year)	1815.6	1868.5	1830.5	1763.6
Water for energy (m^3/capita)	288.6	238.3	212.8	186.8

Source: Adapted from WEC (2010, table 2, p. 51, various data sources).

m^3. The price of desalinated water is therefore closely linked to the energy price, which, despite fluctuations, has been steadily increasing over the past decade (EIA, 2010). However, while such global averages may be interesting in theory, drinking water is so important that local choices of water provision will in practice depend on availability of the resource. Furthermore, desalination produces highly concentrated waste brine streams that must be disposed of. Coastal desalination plants discharge that brine into neighbouring waters, with negative impacts on coastal marine ecology. Inland desalination plants face an equal challenge to find ecologically benign ways to dispose of the brine.

As Table 2.3 shows, wastewater treatment also requires large amounts of energy (WEF, 1997). High-income countries that have stricter discharge regulations install more energy-intensive treatment technologies. Trickling filter treatment, which uses a biologically active substrate for aerobic treatment, is a reasonably passive system, consuming over 250 kWh per ML on average (EPRI, 2002; Stillwell, 2011). Diffused air aeration, as part of activated sludge processing, is a more energy intensive form of wastewater treatment, requiring 340 kWh per ML due to blowers and gas transfer equipment (EPRI, 2002; Stillwell, 2011). More advanced wastewater treatment, utilizing filtration and the option of nitrification, requires 400–500 kWh per ML (EPRI, 2002; Stillwell et al., 2011). In fact, more advanced sludge treatment and processing can consume energy in the range 30–80% of total wastewater plant energy use (Center for Sustainable Systems, 2008).

Treating wastewater sludge through anaerobic digestion can also produce energy through the creation of methane-rich biogas, a renewable fuel that can be used to generate up to 50% of the treatment plant's electricity needs (Sieger and Whitlock, 2005; Stillwell, King and Webber, 2010).

Because wastewater treatment is generally more energy intensive than standard water treatment, the trend towards these higher treatment standards will likely increase the unit energy needs of wastewater treatment in the future for countries moving up in income (Applebaum, 2000). However, it is possible that the introduction of greater energy efficiency will offset the expected increases in energy intensity for stricter treatment standards, limiting the projected growth in electricity use at treatment plants. The higher per capita energy expenditures for wastewater treatment in order to achieve stricter environmental standards is a scenario likely to be repeated in analogous ways throughout all societies achieving affluence; that is, as nations get richer, they will demand more energy. Energy is also used for irrigation of crops. In OECD countries, energy for irrigation account for a small fraction of the total energy embedded in water (heating, treating and disposing of water requires much more energy). However, in non-OECD countries where treating and heating are less common, irrigation takes up a relatively larger share of energy for water.

Water requirements to support growing populations are increasing, and water scarcity will oblige nations to

TABLE 2.3

Average US figures for water production

	Source / treatment type	**Energy use (kWh/million L)**
Water	Surface water	60
	Groundwater	160
	Brackish groundwater	1 000-2 600
	Seawater	2 600-4 400
Wastewater	Trickling filter	250
	Activated sludge	340
	Advanced treatment without nitrification	400
	Advanced treatment with nitrification	500

Note: The table does not include energy used for distribution.
Sources: CEC (2005); EPRI (2002); Stillwell (2010); Stillwell et al. (2010, 2011).

progressively explore unconventional sources of water with larger electricity requirements. Thus, while technologies are steadily becoming more energy efficient (Strokes and Horvath, 2009), this gain in efficiency risks being offset by the increased energy requirements for delivering water from increasingly distant sources and sources disadvantageous due to their location, or treating water that is of lower quality.

2.2.3 Drivers, challenges and responses to the water-energy nexus

As stated earlier, global energy consumption is expected to increase dramatically over the next two decades. This trend is primarily a function of population and economic growth in developing countries. The main challenge with regard to water and energy will be the provision of water resources to ensure that the increased energy needs can be supplied. This need requires policy-makers to promote more efficient and integrated water uses for energy and vice versa. The first step toward such policies will be comprehensive assessments of water availability on a country level. Second, water and energy policies, which are often made in different government departments or ministries, will need to be integrated with policy-makers increasingly working in close coordination.

All the aforementioned trends suggest a potential movement towards water-production methods that are increasingly energy-intensive. Many high-income societies are moving towards more energy-intensive water because of a push by many water utilities for new supplies of water from sources that are farther away and lower quality, and which thereby require more energy to get them to the right quality and location. In addition to treating water to higher standards of cleanliness, societies are also going to greater lengths to transport freshwater from its sources to dense urban areas. These efforts include digging to ever-deeper underground reservoirs, or moving water via massive long-haul projects (Stillwell, King and Webber, 2010).

In politically stable regions, there is a strong possibility that the role of national decision-making frames will decline and that decisions on water and energy may increasingly be subjected to influences at the supranational level, with governments working together in basin organizations and power pools – assuming (as mentioned in Chapter 1) that such processes and related agreements reflect the political economy and institutional capacities of the countries involved. Conversely, there will also likely be an increase in localized measures to supply water and energy to remote locations in order to empower communities and promote sustainable livelihoods. Such measures include small and micro-hydropower and other small-scale renewables to provide electricity for communities (GVEP, 2011), as well as sand dams (Excellent, 2011) and energy-independent pumps for the provision of rural water sources.

There are also technical solutions to more efficient water use in the energy sector. For example, brackish water, mine pool water, or domestic wastewater and dry cooling have been used for cooling power plants (NETL, 2009). Research is also ongoing into the water efficiency of biofuels (Gerbens-Leenes et al., 2008), the energy-efficiency of desalination (AFF, 2002), and the reduction of evaporation from reservoirs.

The water–energy nexus will transcend water use and consumption in mere quantity considerations. Energy production also impacts water quality. Thermal, chemical, radioactive or biological pollution can have direct impacts on downstream ecosystems; where emissions are not sufficiently controlled, considerable amounts of agricultural land may be affected by acid rain. Similarly, where water scarcity obliges nations to use non-traditional sources of water (e.g. desalination, brackish water), choices will need to be sensitive to the water and environmental impacts of the required electricity.

2.3 Industry

2.3.1 Status and trends

Although industry uses relatively little water on a global scale, it nevertheless requires an accessible, reliable and environmentally sustainable supply. It is generally reported that approximately 20% of the world's freshwater withdrawals are used by industry, although this varies between regions and countries. Furthermore, as described in Section 2.2, water withdrawals for industry are most often reported in combination with those for energy. In addition, the water required for small-scale industry and commerce is often confused with domestic consumption. As a result, surprisingly little is known about how much water is actually withdrawn and consumed by industry for its purposed manufacturing, transformation and production needs.

The percentage of a country's industrial sector water demands is generally proportional to the average income level, representing only about 5% of water

> "Surprisingly little is known about how much water is actually withdrawn and consumed by industry for its purposed manufacturing, transformation and production needs."

withdrawals in low-income countries, compared to over 40% in some high-income countries (Figure 2.1). This observation suggests that the level of a country's or a region's economic development is an important driver of its industrial water use, and may ultimately have as much influence on water use as its population growth.

Water management in the industry sector is typically considered in terms of industrial withdrawals and consumption. Total industrial water withdrawals can be calculated as: Water Withdrawal = Water Consumption + Effluent Discharge (Grobicki, 2007).

Industry's total water withdrawal from surface water and groundwater is usually much greater than the quantity of water it actually consumes. Improved water management is generally reflected in overall decreased industrial water withdrawals or increased wastewater treatment, highlighting the connection between higher productivity and lower consumption and effluent discharges and reduced pollution.

The quality of water required by industry for specific needs can vary considerably. Water of lesser quality may be adequate for many industries, facilitating the use of recycled and reclaimed water. Conversely, some industries may have water quality requirements more demanding than those for drinking water; for example, food processing. Pharmaceutical and high technology industries can require very high-quality water, necessitating additional treatment of water from primary supplies. Other sectors, such as tourism, power generation and transportation, can also have differing water quality requirements.

The water quality of effluent discharges can have very significant environmental impacts, particularly on regional and local scales (UNEP, 2007). Small-scale industries such as agro-processors, textile dyeing, abattoirs and tanneries can cause the presence of toxic pollutants in local water resources. Not only do the pollutants make the water non-potable, but they also kill fish, which are a source of protein for many poor people. Certain toxic chemicals enter the food chain when polluted water or untreated wastewater from industries is used for agriculture. Industrial contamination tends to be more concentrated, more toxic, and often harder to treat than pollutants from other sectors or activities. The persistence of these contaminants, and their rate of movement though the environment and hydrological cycle, can often involve long periods of impaired water resources (UNEP, 2007).

In addition to considering water quantity and quality concerns, industry must also use water efficiently and wisely, even as it seeks to augment its economic output and profit. This concept of water productivity refers to the value that can be obtained from each unit of water used. The third edition of the *World Water Development Report* (Chapter 7) reported values ranging from well over US$100 to less than US$10 per m^3 of water used, depending on the country. As technology improves, industrial water productivity also typically rises. Thus, low productivity may indicate that the water is either under-priced or simply abundant, which results in cost becoming an insignificant factor. High productivity is linked to high water re-use, with reduced water withdrawals. Water productivity also can be of considerable interest to decision-makers concerned with water allocations.

In addition to water withdrawals, significant industrial interventions affecting the hydrological cycle include effluent discharges into surface water bodies, contaminant infiltration into groundwater, and atmospheric distribution and fallout of contaminants into water bodies. One approach to decreasing or avoiding environmental degradation from industrial activities, even as industry continues to develop, is through cleaner production and sustainability practices. Cleaner production has many facets, and one of its main objectives is to move toward zero effluent discharges, with industry working to convert wastewater streams into useful inputs for other processes, industries and industrial clusters.

2.3.2 External drivers

Industry is strongly influenced by external drivers that, indirectly, can add complexity and uncertainty to industry water needs. Economic growth and development are the overall main drivers of industrial water use, and that relationship is reciprocal: while economic forces affect water, the availability and state of water resources also influences economic activity. Ecosystem stress, societal values and security are also important drivers, but are typically more local in nature.

International trade – which a driver for industry and water – requires that exports from a source country meet environmental regulations in the destination country. A number of global Multilateral Environmental Agreements (MEAs), such as the Basel Convention,[4] have also resulted in global standards. Developing countries in particular can face trade hurdles in meeting the environmental requirements of developed countries, including ISO certifications, environmental management systems (EMS) and corporate social responsibility (CSR), which could be seen by some as non-tariff barriers to trade. Thus, industries in developing countries can be subjected to stricter, explicit and implicit international requirements, as well as some control, by the multinational companies to which they supply goods or services. However, these requirements can in turn lead to better product manufacturing standards, including energy efficiency and climate change (carbon footprint) considerations, with industry benefiting from better management (including water resources management) and resulting increased efficiency. Finally, the focus on 'green growth' and the 'green economy' (see Section 12.1) at the Rio+20 Summit in 2012 will likely lead to agreements among member states on the adoption of standards and/or protocols, which will in turn have significant implications for industry. The challenge and opportunity for business is to understand the concrete possibilities of a green economy, with its opportunities and risks for its many sectors and different national contexts. Governments will need to work collectively to ensure the prevention of pollution havens in countries with poor enforcement capacities.

The industrial utilization of water resources – including water supply quality and wastewater treatment – is greatly impacted by technological innovation, which can lead to cleaner production and sustainability. Assuming appropriate technologies are available to all (a situation not necessarily applicable to local industries in developing countries), water treatment constraints are primarily a function of cost rather than a lack of technical capability to achieve high-quality water. Although revolutionary technological breakthroughs for water treatment seem unlikely at present, there are nevertheless many incremental technological advances that often bring cost reductions, consistent with a primary industry goal of ensuring the most economic system for achieving required water quality.

In the past, water has been considered a relatively certain component of industrial processes. Indeed, it has been typically assumed that the needed water supply would be easy and relatively cheap to secure. Wastewater discharges have been more of a challenge, although effluent discharges were permissible provided water quality (or treatment) standards were achieved. The recent number of new external drivers on water and its management, however, has now made water use a much riskier proposition for industry (Figure 2.7). Effective operation of an industry requires a sustainable supply of water in the right quantity, of the right quality, at the right place, at the right time and at the right price (Payne, 2007). Industry will find itself increasingly competing for limited water resources as water demands and consumption increase in all sectors, particularly agriculture with its substantial water needs. Thus, all these factors are now subject to greater uncertainty.

Water scarcity is viewed as an increasing business risk, with industrial water supply security dependent on sufficient resources. This problem is compounded by geographic and seasonal variations, as well as water allocations and competing water needs in a given region (e.g. agriculture vs drinking water or residential supply vs industry), a situation that may be beyond the control of industry. This is especially true for transboundary water situations, where the needs of two or more countries may conflict or overwhelm water availability.

Water quality risks associated with both water supply and effluent discharges can affect industry, thereby restricting industrial expansion. In terms of water supply, it has been noted that many sectors require high-quality water, thereby necessitating additional water treatment. In cases of contaminated surface or groundwater supplies, industry faces increased costs associated with additional water treatment needs. Although this requirement may well prompt industry to more strongly consider using reclaimed or recycled water, it will most likely weigh on decisions regarding the location of a company's industrial activities.

In terms of industrial wastewater discharges, the vast majority in developing countries is discharged with little or no treatment (WWAP, 2009). Thus, there is considerable pressure on industry to clean its effluents. While compliance will doubtless become stricter and more onerous, the actual criteria and severity of standards vary by jurisdiction. An associated risk is investing in new treatment technology that may subsequently become obsolete within only a few years. Moreover, industrial accidents, such as uncontrolled discharges, may be the result of economic and other drivers that forced industrial expansion more quickly than was justifiable in a given situation, possibly utilizing unproven technology and/or in sensitive locations. Poor water quality, therefore, can restrict industrial expansion. Likewise, industrial expansion can place unsustainable strain on water resources.

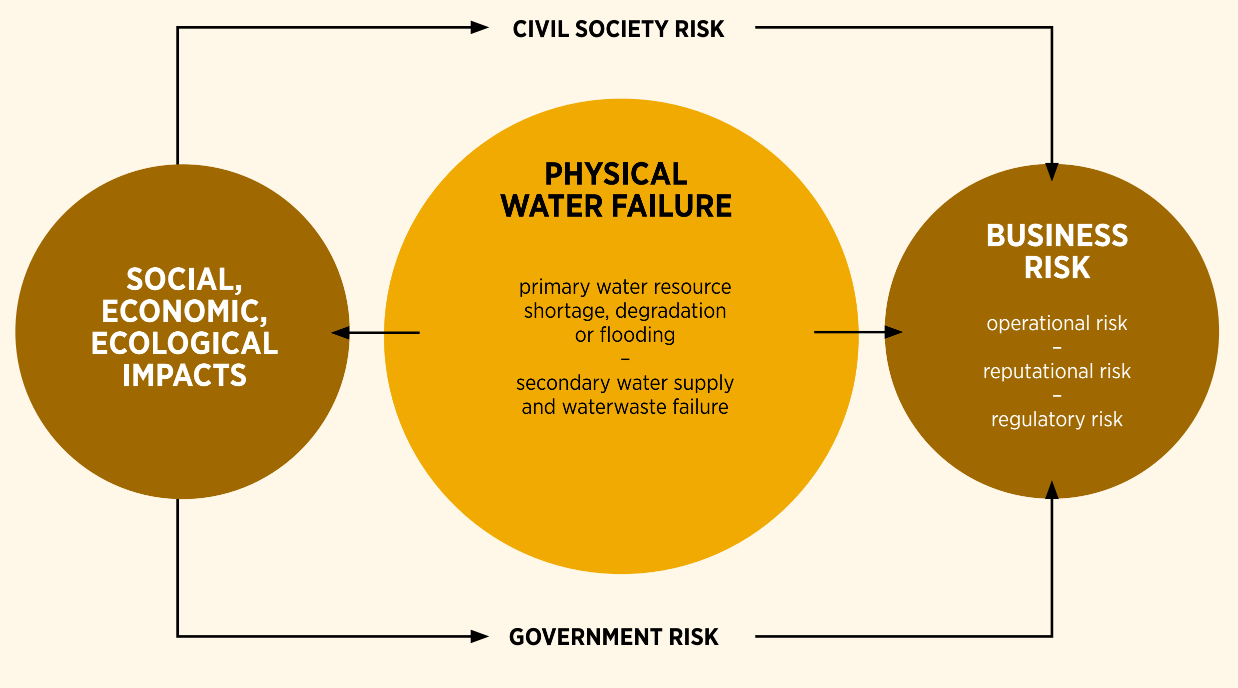
Government policies regarding water must often respond to multi-faceted agendas on the national to local level. Government priorities and policies inevitably change over time. These changes, particularly unpredictable ones, can make it difficult for industry, especially multi-national companies, to locate successfully in certain countries. For example, poor policy decisions can lead to over-use of water resources in some locations and under-use in others. Furthermore, governmental perceptions of water risks in a given case can be at odds with those of industry. Environmental concerns and pressures from the public, special interest groups and business can further influence government decisions regarding water.

2.3.3 Adaptations and options for solutions

Undoubtedly, business and industry can play a leading role in sustainable water practices. To successfully adapt to water scarcity – which can involve not only a lack of water but also poor water delivery infrastructure and/or poor water management – a business or industry must have accurate knowledge of its specific

FIGURE 2.7

Inter-relationship of water risks among business, government and society



Sources: SABMiller Plc and WWF-UK (2009, fig. 2, p. 5, refer to www.sabmiller.com/water).

water needs. For example, establishing water accounting techniques and measuring water impacts can allow an industry to more readily identify potential areas of increased water use efficiency; however, the accumulation of accurate data and a consistent approach to water measurements and monitoring are needed to achieve this end. Another approach to increasing water productivity involves 'doing more with less', ideally moving toward a goal of zero discharge (i.e. utilizing a closed-loop production system). This objective underpins the recent development of industrial ecology (eco-innovation) as a means of addressing the inter-relationship of industrial and economic systems to natural systems.

Industry is generally accustomed to having water available at a relatively inexpensive price. Increasing water scarcity, however, will result in higher charges, including additional charges for water treatment and discharge. There is an argument for developing a different price structure for industrial water use; that is, requiring industry to pay more per unit of water than the public, as well as increasing amounts per unit with increasing water use. The impacts of such practices on industry will naturally promote increased water use efficiency, since the economic realities of the cost of water will increase the price of the associated products. These effects could have an impact on the industrialization process in developing countries where water costs are usually low if not non-existent, and the concepts of water productivity and cleaner production are either unknown or sidelined in efforts to make goods and create jobs.

Against this background, the embracing challenge is for industry to play its appropriate role in effectively addressing unsustainable exploitation and contamination of freshwater resources around the world. This includes the impacts of industry on those supplies and the challenge of mitigating them for the benefit of all water users and the environment – a goal that must be approached within the context of corporate, social and environmental responsibility. Although there are ways to address the issues, risks and challenges of water productivity, they require effective implementation and oversight, including the application of environmental technologies to help conserve the natural environment and resources, as well as to curb the negative impacts of human activities. Moreover, information without action and public disclosure does not constitute real progress. Focusing on meeting this challenge will provide industry with an opportunity to increase productivity, efficiency and competitiveness in a sustainable way.

> "Effective operation of an industry requires a sustainable supply of water in the right quantity, of the right quality, at the right place, at the right time and at the right price."

The problems surrounding water productivity in industry and broader global water concerns are interrelated. As such, they require integrated management, strategy, planning and actions to provide effective solutions. To meet these challenges, industry must first look to its management priorities and style, and its company values and culture, to encourage a positive response from within its own sphere. An integrated management approach, promoting proactive measures by industry, including consideration of the needs and interests of affected stakeholders and the environment, will not only anticipate the future, but actually help shape it (BSR and Pacific Institute, 2007). Innovation, investment and collaboration are key elements to addressing this goal, and achieving it will require a strategic approach, including the following points:

- A measure of industry's operational and supply-chain water use ('you can't manage what you don't measure').[5] An accurate water impact assessment considers a product's water content, and the less obvious inputs and uses of water in its production (virtual water). A further determination is where and when the water is used, and for what purpose. This determination requires accurate data and a consistent approach to measurement and monitoring.
- A measure of industry exposure to water risks involving a risk assessment that evaluates relevant hydrological, economic, social, political and environmental factors in different contexts.

- A corporate water policy that embraces strategies ranging from corporate values to communication, and which may include:
  - Promoting CSR
  - Encouraging cradle-to-cradle industrial operations[6]
  - Using the precautionary principle to promote action, develop options and assist decisions
  - Introducing EMS
  - Setting measurable goals and targets with regard to water efficiency, conservation and impacts, accompanied by public disclosure of relevant data
  - Decoupling material and energy consumption, and integrating energy needs and water requirements
  - Constant and effective communication with the public and local stakeholders regarding the economic and environmental costs and benefits of various industrial policies, strategies and measures
  - Collaboration with government agencies
  - Becoming involved with like-minded companies through such avenues as the CEO Water Mandate and the World Business Council for Sustainable Development, as a means of sharing and promoting successful actions, thereby assuming a proactive leadership role in sustainable practices
- An innovation implementation strategy involving both ongoing initiatives needing reinforcement and others that might be considered for the future, including:
  - Decreasing water use and increasing water productivity through water audits, zero discharge and water optimization techniques, water recycling and reuse, addressing water losses from aging infrastructure, and full and consistent monitoring activities
  - Introducing new technologies, including adapting new environmental technologies and incorporating natural water treatment systems, transferring environmentally sound technologies in conjunction with environmental management accounting (EMA)
  - Employing industrial ecology (eco-innovation), including employing environmental design into industrial design and planning, investing in environmental and ecological restoration, and using a life-cycle approach within the context of a closed-loop system

2.4 Human settlements

2.4.1 Urbanization and population trends

Between 2009 and 2050, the world population is expected to increase by 2.3 billion, from 6.8 to 9.1 billion (UNDESA, 2009). At the same time, urban populations are projected to increase by 2.9 billion, from 3.4 billion in 2009 to 6.3 billion total in 2050. Thus, the urban areas of the world are expected to absorb all of the population growth over the next four decades, while also drawing in some of the rural population. Furthermore, most of the population growth expected in urban areas will be concentrated in the cities and towns of less developed regions. Asia's population is projected to increase by 1.7 billion; Africa has a projected urban population gain of 0.8 billion; and Latin American and the Caribbean urban populations are projected to grow by 0.2 billion. In 1950, New York City and Tokyo were the only two cities with populations exceeding 10 million. By 2015, it is expected that there will be 23 such cities of which 19 will be in developing countries. Projections indicate a continuing increasing trend of urbanization in developing countries. By 2030, it is anticipated that the urban population in developing and developed countries will amount to 3.9 billion and 1 billion respectively. Population growth is therefore becoming largely an urban phenomenon concentrated in the developing world (UN-Habitat, 2006).

> Migration from rural to urban areas poses a major challenge for city planners; extending basic drinking water and sanitation services to peri-urban and slum areas to reach the poorest people is of the utmost importance to prevent outbreaks of cholera and other water-related diseases in these often overcrowded places. (WHO/UNICEF, 2006, p. iii)

Slums generally present a set of unique problems, including poor housing conditions, inadequate access to safe water and sanitation, overcrowding and insecure tenure; thus, the welfare of those living in these areas are seriously impacted (Sclar, Garau and Carolini, 2005). The relation between climate change and slum areas is cause for alarm in terms of disaster vulnerability resulting from meteorological phenomena. To complicate matters further, slums are usually built on dangerous land, unsuitable for human settlement. For example, shantytowns near Buenos Aires are built on flood-prone land, and residents are therefore forced to make a difficult choice between their safety and health and their need for shelter (Davis, 2006). In some cities, for example Mumbai, nearly half the urban population reside in slums and shantytowns (Stecko and Barber, 2007). As is evident from Figure 2.8, not only is the slum population rising, it is also highly concentrated in developing countries, especially in sub-Saharan Africa, Southern Central and Eastern Asia. In Latin America and the Caribbean, a significant reduction is observed in the proportion of the urban population living in marginal areas – from 37% (110 million people) in 1990 to 25% (106 million) in 2005 (United Nations, 2010).

Cities in developing countries face enormous backlogs in shelter, infrastructure and services, as well as insufficient water supply, deteriorating sanitation and environmental pollution. Population growth and rapid urbanization will create an even greater demand for water while decreasing the ability of ecosystems to provide more regular and cleaner supplies.

Climate change is posing an additional challenge to urban water supplies by changing water availability and exacerbating water-related disasters such as floods and droughts. For example, tropical storms were rare in Ho Chi Minh City, Viet Nam, until fairly recently. But over the past 60 years, 12 large tropical storms – including Vae (1952), Linda (1997) and Durian (2006) – have affected the city. Typically, these storms bring heavy rainfall, increased localized flooding and storm surges along the coastal areas, causing serious extensive flooding of 1.0 to 1.2 m. Of the Ho Chi Minh City's 322 communes and wards, 154 have a history of regular flooding. These floods cover close to 110,000 ha and affect some 971,000 people (12% of the population). It is predicted that by 2050, such regularly flooded areas will have increased to 177 (55% of the city's communes) covering 61% of the city area (ADB, 2010).

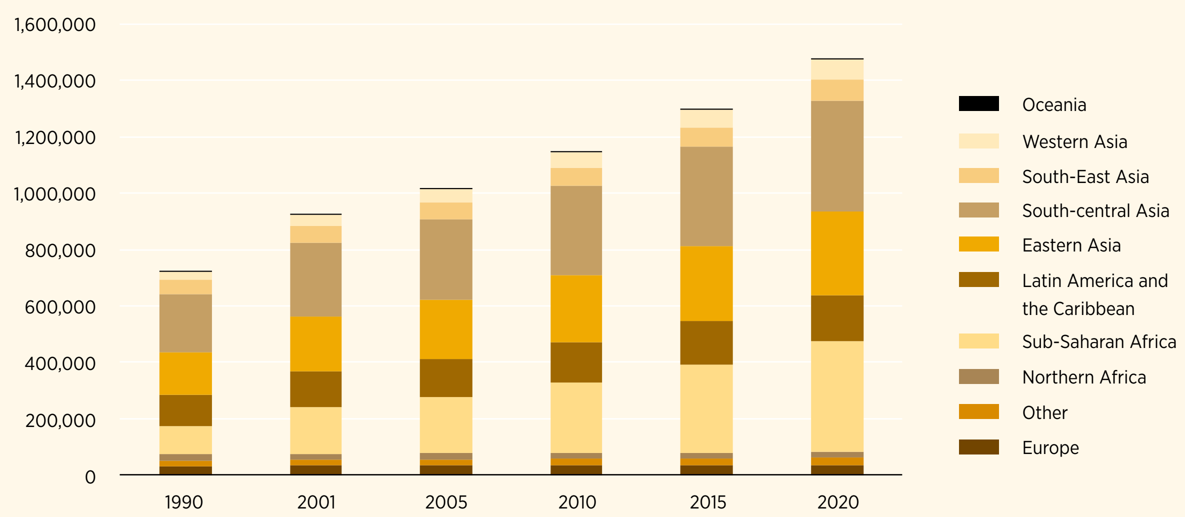
2.4.2 Water supply and sanitation coverage: Keeping up with urban growth

Worldwide, 87% of the population gets its drinking water from improved sources, and the corresponding figure for developing regions is also high at 84%. Access is far greater, however, in urban areas (at 94%), while only 76% of rural populations have access to improved sources (WHO/UNICEF, 2010). However, these estimates do not take into consideration service quality (e.g. intermittent supply, disinfection) or affordability. Also, given the lack of reliable data concerning human populations in marginalized communities (i.e. slums), governments and international agencies are likely to significantly underestimate the number of urban dwellers lacking adequate provision for drinking water. Furthermore, this number is actually increasing as rapid urbanization continues in many regions (UN-Habitat, 2003, 2010).

In 2010, a reported 2.6 billion people in the world did not use improved sanitation facilities (WHO/UNICEF, 2010). Of the approximately 1.3 billion people who gained access to improved sanitation during the period 1990–2008, 64% live in urban areas. However, urban areas, although better served than rural areas, are struggling to keep up with urban population growth

FIGURE 2.8

Slum population by region, 1990–2020 (thousands)



Source: Produced by UN-Habitat based on data available at http://ww2.unhabitat.org/programmes/guo/documents/Table4.pdf (published in State of the World's Cities Report 2001).

(WHO/UNICEF, 2010). Again, projected demographic growth in urban areas gives rise for concern: if efforts continue at the current rate, improvements in sanitation facility coverage will only increase by 2% – from 80% in 2004 to 82% in 2015 (an additional 81 million people) (WHO/UNICEF, 2006).

A comparison of the latest estimates from 2008 with those of 2000 indicates a deterioration in both water and sanitation coverage in urban areas. Over those eight years, in cities and towns of all sizes, the number of people without access to tap water at home or in the immediate vicinity increased by 114 million, and the number of people without access to private sanitary toilets (basic sanitation) increased by 134 million. In both cases, this means an increase of 20% in the number of individuals living in cities who lack access to basic facilities (AquaFed, 2010).

Keeping up with the population increase in cities and maintaining current water supply and sanitation (WSS) services coverage levels for 2015 requires serving 700 million urban dwellers over the coming decade (WHO/UNICEF, 2006). At present, the urban population is increasing faster than the speed of improvement in WSS services; however, current efforts to address this challenge are not insignificant (UNDESA, 2009). For example, the total percentage of individuals with access to improved WSS declined between 2000 and 2008, but the number of urban residents with access to tap water are estimated to have grown by 400 million (AquaFed, 2010).

Other improvements have been made, such as in Northern Africa, South-East Asia, Eastern Asia, and Latin America and the Caribbean, where access to improved water supply and sanitation has significantly increased (WHO/UNICEF, 2010). However, up to 50% of the urban population in Asia overall still lacks adequate provision of water, and up to 60% lacks adequate sanitation (UN-Habitat, 2010). In sub-Saharan Africa, the numbers of urban dwellers without access to tap water has increased by 43% in eight years.

2.4.3 Pressure from urban areas on water

Water withdrawals

Relative to other sectors, water withdrawal for urban use is low: industrial (including energy) use is around 20%, domestic use is about 10%, and abstraction for agriculture is as high as 70% globally (WWAP, 2009). Increasing water demands are leading to over-abstraction from groundwater, areas outside cities and upstream watershed areas, as well as from rural areas, depriving other users and challenging ecosystem functions.

In areas where surface water is not readily available, groundwater is the primary water source (UNEP/GRID-Arendal, 2008). Excessive groundwater abstraction is resulting in falling water tables, water quality degradation and land subsidence (see Section 3.2.1), as is the case in several cities in Asia – including Bangkok, Beijing, Chennai, Manila, Shanghai, Tianjin and Xian (Foster, Lawrence and Morris, 1998).

The supplying aquifer in Mexico City fell by 10 m as of 1992, resulting in land subsidence of up to 9 m. Over-abstraction in coastal areas results in saltwater intrusion: in Europe, 53 out of 126 groundwater areas show saltwater intrusion, mostly in aquifers that are used for public and industrial water supply (Chiramba, 2010). A growing number of large urban centre aquifers are also facing pollution from organic chemicals, pesticides, nitrates, heavy metals and water-borne pathogens (UNEP/GRID-Arendal, 2008).

Pollution and wastewater

Urban settlements are also the main source of point-source pollution. Urban wastewater is particularly threatening when combined with untreated industrial waste. In many fast-growing cities (small and medium-sized cities with populations of less than 500,000), wastewater infrastructure is non-existent, inadequate or outdated. For example, the city of Jakarta, with a population of 9 million, generates 1.3 million m^3 of sewage daily, of which less than 3% is treated. In contrast, Sydney, with a population of 4 million, treats nearly all of its wastewater (1.2 million m^3 per day) (Chiramba, 2010). Chile made impressive progress in urban wastewater treatment, increasing it from only 8% in 1989 to almost 87% in 2010 (SISS, 2011), with plans to treat all urban wastewater in 2012 (Pickering de la Fuente, 2011). Worldwide, it is estimated that over 80% of waste water worldwide is not collected or treated (Corcoran et al., 2010). As shown in Figure 2.9, the ratio of untreated to treated wastewater reaching water bodies for 10 regions in significantly higher in developing regions of the world.

Wastewater contributes to increase in eutrophication and dead zones in both oceans and freshwater. Dead zones affect about 245,000 km^2 of marine ecosystems, with consequent impacts on fisheries, livelihoods and the food chain. Discharge of untreated wastewater shifts problems to downstream areas. In coastal areas, seagrass ecosystems/habitats are damaged, and invasive species are increasing in estuarine ecosystems.

The economic recession of the 1990s combined with decline in highly polluting industries led to reduced discharge of wastewater and pollutants in Eastern Europe, relieving some of the pressure on river quality in many areas. It also resulted in the breakdown of water supply and wastewater treatment systems, and consequently heavy pollution of rivers and drinking water supplies in downstream cities in industrial and mining regions. Major losses of seagrass habitats occurred in Australia, Florida Bay (USA) and the Mediterranean, while increases occurred in the Caribbean and Southeast Asia (Chiramba, 2010).

Illegal and unreported releases of untreated wastewater continue to be an issue all over the world. Recently, for example, the city of Revere, Massachusetts has agreed to spend approximately US$50 million to reduce illegal discharges of raw sewage overflows into the environment from its wastewater collection system and separate storm sewer system, and to pay a penalty of US$130,000 for the Clean Water Act violation (CTBR, 2011) Corcoran et al. (2010) report that up to 90% of wastewater in developing countries flows untreated into rivers, lakes and highly productive coastal zones, threatening health, food security and access to safe drinking and bathing water.

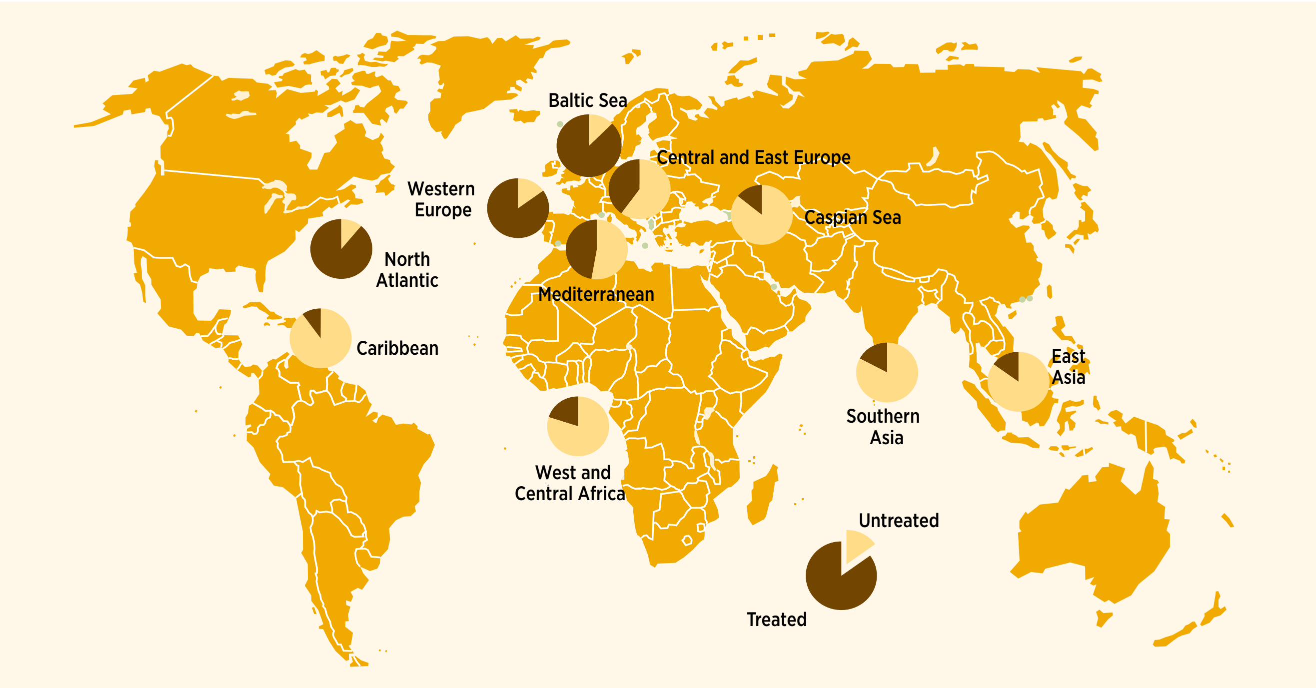
2.4.4 Water management in urban areas

Integrated urban water management

Water management in urban areas can benefit from more comprehensive urban planning and integrated urban water management (IUWM). IUWM involves managing freshwater, wastewater and stormwater as links within the resource management structure, using an urban area as the unit of management. The objective of such an approach is to facilitate the multi-functional nature of urban water services in order to optimize the outcomes of the system as a whole. The approach encompasses various aspects of water management, including environmental, economic, technical and political, as well as social impacts and implications. Issues, options and examples for arid, semi-arid and humid regions can be found in Tucci et al. (2010) and Mays (2009).

FIGURE 2.9

Ratio of treated to untreated wastewater discharged into water bodies



Note: Ratio of wastewater treatment (March 2010).
Source: UNEP/GRID-Arendal (http://maps.grida.no/go/graphic/ratio-of-wastewater-treatment1, adapted from a map by H. Alhenius with sources UNEP-GPA [2004]).

Urban agriculture

Urban and peri-urban agriculture (UPA) is the safe production of agriculture and cattle products in and around cities. UPA is estimated to involve 800 million urban residents worldwide (Smit et al., 1996) and contributes to solving several urbanization problems by enhancing food availability, particularly of fresh produce; providing employment and increasing income, food security and nutrition of urban dwellers; and greening cities and also recycling wastes. However, these areas can use water of lesser quality that contains nutrients beneficial to agriculture while preventing pollution downstream. UNEP estimates that sewage water irrigates about half the gardens, roadside verges and small fields where food is grown in the world's urban and peri-urban areas. A new look is being taken at how to use this traditional resource safely (Corcoran et al., 2010).

Urban food security projects are being undertaken in large cities of the Middle East and Africa with local partners, including women's farmers groups. For example, in Istanbul, an urban agriculture project supports and trains unemployed, poor women of Gürpinar to develop urban agricultural activities (e.g. composting, processing, marketing and organization) to help sustain them in the future (ETC Urban Agriculture, 2011). A study by Hovorka et al. (2009) provides evidence for the important role women play in household food production, growing vegetables in gardens and vacant urban spaces, raising animals, and trading in fresh and cooked foods.

Infrastructure and maintenance

> Protecting [and financing] the infrastructure used to treat and transport water (including sources, treatment plants and distribution systems) is an important step in ensuring safety in public health and the environment. However, in most cities worldwide, there has been years of neglected maintenance to water storage, treatment and distribution systems. A large proportion of this infrastructure is over 100 years old, placing it at increased risk for leaks, blockages and malfunctions due to deterioration (Vahala, 2004). Higher rates of water leakage mean greater water losses and higher chances of infiltration and ex-filtration of water. This will create higher chances of drinking water contamination and outbreak of water-borne diseases. (Vairavamoorthy, 2008, p. 5)

The cost of rehabilitation of water infrastructure is increasing substantially due to their deterioration over the world. In the USA, for example, the American Society of Civil Engineers forecasts a funding gap of US$108.6 billion over five years for drinking water and wastewater infrastructure system improvements and operations (ASCE, 2009). An earlier study (Olson, 2003) of urban water supply networks in 19 US cities revealed that 'pollution and deteriorating, out-of-date plumbing are sometimes delivering drinking water that might pose health risks to some residents' (NRDC, n.d.).

The deterioration process is more severe for developing countries, due to poor construction practices, little or no maintenance and rehabilitation activities, lack of records, and operation at higher capacities than design. The water supply services sector in sub-Saharan Africa, for example, has long suffered from poor performance of its public water utilities. Apart from service coverage of less than 60% (WHO/UNICEF, 2006), other problems that plague water utilities include high unaccounted-for water (UfW), which often averages between 40% and 60%, and overstaffing (Mwanza, 2005). Moreover, service providers are often confronted with financial problems due to a combination of low tariffs, poor consumer records and inefficient billing and collection practices (Foster, 1996; Mwanza, 2005; International Bank for Reconstruction and Development/World Bank, 1994).

In addition, the informal sector often supplies water to households and is unregulated and difficult to monitor. The poorest families in urban areas, often living in informal settlements lacking public services, often end up paying the most for drinking water that may be unsafe (Briscoe, 1993; Jouravlev, 2004; Garrido-Lecca, 2010). The highest risk for health occurs where there is a lack of basic access to safe drinking water (Howard and Bartram, 2003). The same families that purchase inexpensive drinking water from street vendors may also have poorer hygiene. A study in Jakarta, for example, showed that 55% of drinking water samples taken from households in the slums of east Jakarta had faecal contamination (Vollaard et al., 2004).

Cities of the future

Initiatives are emerging worldwide to address the need for improved and comprehensive urban water planning, technologies, investment and associated operations. The International Water Association

(IWA), for example, has launched the 'Cities of the Future' programme, which focuses on water security for the world's cities, and how the design of cities – including the water management, treatment and delivery systems that serve them – could be harmonized and re-engineered to minimize the use of scarce natural resources, and increase the coverage of water and sanitation in lower and middle-income countries. The Istanbul Water Consensus for Local and Regional Authorities, endorsed in 2009 during the fifth World Water Forum in Istanbul, is a local and regional government declaration that asks signatory cities to commit to developing water management strategies suitable to work towards the Millennium Development Goals (MDGs); and to address urbanization, climate change and other global pressures at local level. At the national level an example comes from a highly urbanized nation, Australia, where the government has recently re-evaluated the urban water sector within the framework of the National Water Initiative, and has identified reforms and changes in policy and institutional settings (National Water Commission, 2011).

Water management together with land-use planning for urban areas will need to become more efficient to meet current and growing demand through technology, investment, and comprehensive and integrated planning for multiple users. Water education can play a very important role in this regard by changing behaviour and attitudes in wider society. The Human Values-Based Approach to Water, Sanitation and Hygiene Education promoted by UN-Habitat is a proven approach that can be incorporated into current educational curricula without imposing a heavy burden on teachers and learners.

Investing in drinking water supply and sanitation systems, promoting efficiency in service provision, providing subsidies for the poor and protecting water resources from pollution and over-extraction are imperative to ensuring access to safe water for all, particularly poor urban populations who are too often left behind.

2.5 Ecosystems

Ecosystems underpin the availability of water, including its extremes of drought and flood, and its quality. Water management often involves trade-offs – and often the transfer of risks – between ecosystem services. Water demand by ecosystems is determined by the water requirements to sustain or restore the benefits for people (services) that we want ecosystems to supply. Better-integrated water management and more sustainable development require the focusing of greater attention on ways to resolve the increasing competition for water between ecosystems and socio-economic sectors.

Human versus 'environment' or 'ecosystem' demands for water have been the subject of debate for decades. A root cause of early disagreement has been the perception that these are somehow different subjects, thereby promoting conflicts between development and environment or nature conservation interests. Over recent years, there has been better convergence of interest through improved recognition that the water used to maintain the environment, or ecosystem integrity, is in fact also a means to support human needs through sustaining the benefits to people that a healthy ecosystem delivers. Such benefits are termed 'ecosystem services' (Box 2.2).

Ecosystems – including, for example, forests, wetlands and grassland components – lie at the heart of the global water cycle. All freshwater ultimately depends on the continued healthy functioning of ecosystems, and recognizing the water cycle as a biophysical process is essential to achieving sustainable water management (Figure 2.10).

Historically, some have regarded ecosystems as an unproductive 'user' of water. This is fundamentally incorrect as ecosystems do not use water – they recycle it. But perceptions are shifting towards managing human interactions with ecosystems ('the environment') in order to support water-related development goals. All terrestrial ecosystem services, such as food production, climate regulation, soil fertility and functions, carbon storage and nutrient recycling, are underpinned by water, as are, of course, all aquatic ecosystem services. Water availability and quality, in terms of direct use by humans, are also ecosystem services, as are the benefits ecosystems offer to mitigate the extremes of drought and flood. Most ecosystem services are interrelated, and particularly so through water. Decisions that favour increasing one service over, or at the expense of, another therefore inevitably involve trade-offs. Importantly, this trading between ecosystem services can also carry with it the transfer of risks through associated ecosystem changes. Some examples of such trade-offs are provided in Section 8.3.

Biodiversity is also sometimes regarded as an ecosystem service as it does have direct value (i.e. cultural/aesthetic/recreational benefit, existence value); however, it is more widely regarded as underpinning the functioning of ecosystems and therefore their ability to continue to sustain service delivery (Box 2.3).

BOX 2.2

Water and ecosystem services

Ecosystem services (benefits for people) can be grouped in various ways. The Millennium Ecosystem Assessment has provided the most comprehensive assessment of the state of the global environment to date, and has classified ecosystem services as follows:

Supporting services: The services necessary for the production of all other ecosystem services. Supporting services include soil formation, photosynthesis, primary production, nutrient cycling and water cycling.

Provisioning services: The products obtained from ecosystems, including food, fibre, fuel, genetic resources, biochemicals, natural medicines, pharmaceuticals, ornamental resources and freshwater.

Regulating services: The benefits obtained from the regulation of ecosystem processes, including air quality regulation, climate regulation, water regulation, erosion regulation, water purification, disease regulation, pest regulation, pollination and natural hazard regulation (including extremes in water availability).

Cultural services: The non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences, thereby taking account of landscape (including waterscape) values.

Water is multi-dimensional in the context of ecosystem services. Its availability and quality are products (services) provided by ecosystems. But water also influences how ecosystems can function and therefore underpins ***all*** other ecosystem services. This gives water paramount importance in managing ecosystems so as to deliver benefits to people.

The Millennium Ecosystem Assessment concluded that human development had tended to promote certain services (especially provisioning services) at the expense of others. This has led to an imbalance in services and indicates a path towards decreasing sustainability.

Source: Adapted from Ecosystem Services (2011, Crown Copyright).

The subject of 'water demand' by ecosystems therefore involves identifying ecosystem 'deliverables' and managing water accordingly. The valuation of these services is central to this, and the advances made over the past 20 years provide a range of techniques that can be used in practice. Even for many terrestrial ecosystems (such as forests), values related to water services outstrip more conspicuous benefits (such as timber products and carbon storage). For example, the water-related services provided by tropical forests include regulation of water flows, waste treatment/water purification and erosion prevention. These collectively account for a value of up to US$7,236 per ha per year – more than 44% of the total value of forests, exceeding the combined value of carbon storage, food, raw materials (timber), and recreation and tourism services (TEEB, 2009).

Comprehensive valuation of ecosystem services is not yet a precise science, but the process illuminates the potential stakes and provides good comparative indications of where priorities should lie (see Chapters 21 and 23 for further information on valuing ecosystem services). While some services are difficult to value, others are easier because information on how much their losses cost is available. A very large proportion of the capital investment and operational cost of physical water infrastructure is in effect expenditure that compensates for the loss of an ecosystem service, which can therefore

BOX 2.3

Biodiversity increases ecosystem efficiency

Controlling nutrient levels in watersheds is a primary objective of most water management policies. Much research has shown that ecosystems with more species are more efficient at removing nutrients from soil and water than ecosystems with fewer species. Recent experiments have demonstrated, for example, that different forms of algae dominate each unique habitat in a stream, and the more diverse communities achieved a higher biomass and greater nitrogen uptake. When habitat diversity was experimentally removed, these biofilms collapsed to a single dominant species and nutrient cycling efficiency decreased. Maintaining both the physical (habitat) and biological diversity of streams therefore helps to buffer ecosystems against nutrient pollution, demonstrating that the conservation of biodiversity is a useful tool for managing nutrient uptake and storage.

Source: Cardinale (2011).

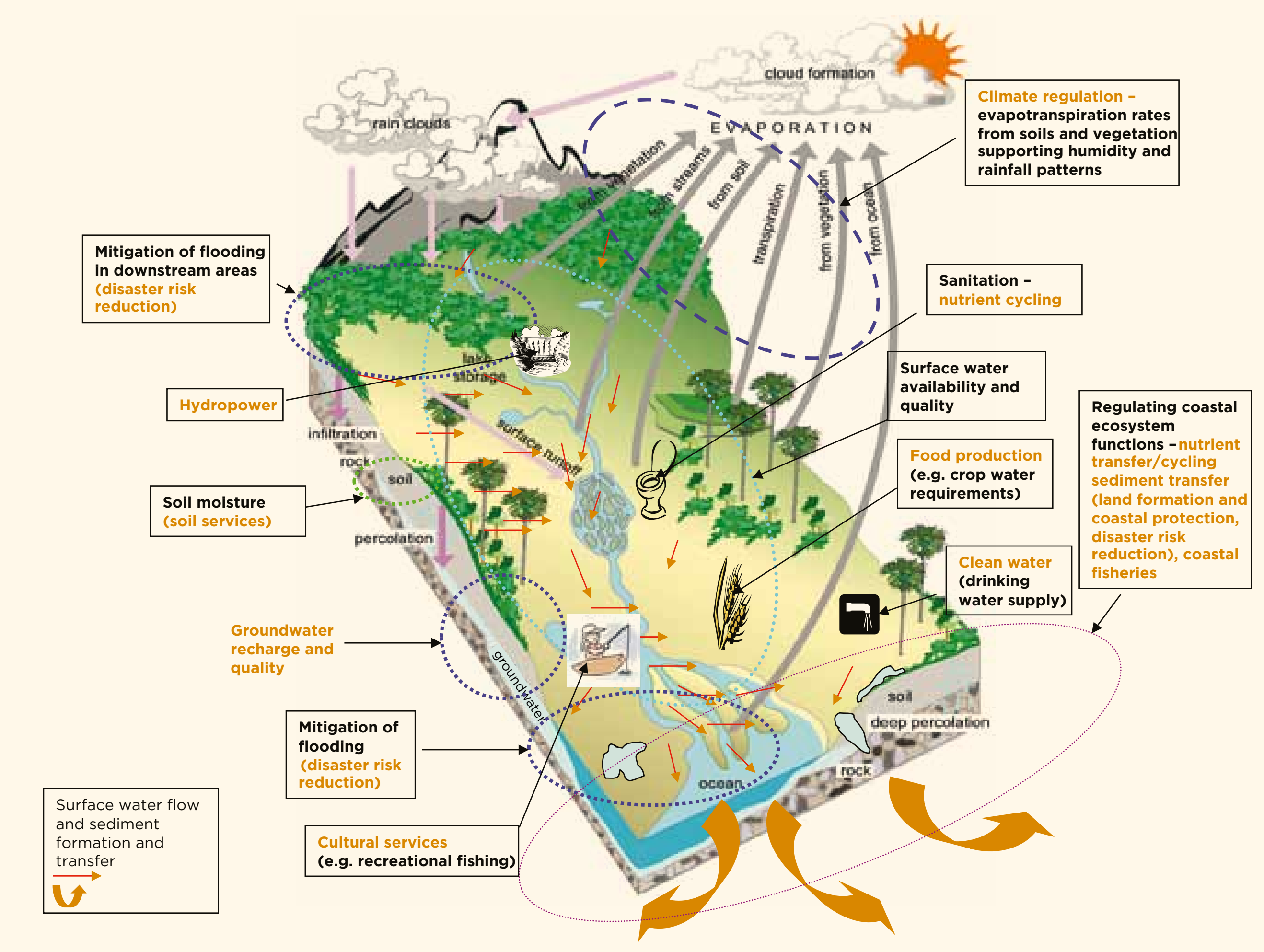
be used to indicate the value of that service. The classic example is water quality whereby, with very few exceptions, healthy ecosystems deliver clean water and any subsequent investment in treating a human-induced water quality problem can be attributed to the loss of this ecosystem service originally provided for free.

Water 'demand' by ecosystems, to a large extent, can therefore be assessed based on socio-economic criteria, as for any other use. Indeed, allowing water to underpin ecosystem health and therefore service delivery can result in net economic gains, or cost savings, very visible on financial balance sheets (Box 2.4).

An increasingly useful hydro-ecological expression for the quantity of water needed for healthy ecosystem functioning is 'environmental or minimum flow'. The approach originates from the consideration of flows required to maintain the life cycles of biodiversity in rivers, as used most frequently in relation to water allocation and the design and operation of water infrastructure such as large dams. But in the past decade or so, the concept of environmental flow, and the science underpinning it, has shifted towards including socio-economic considerations by assessing requirements to maintain or restore the desired levels of ecosystem services in a given area (Box 2.5). The approach is therefore becoming a more powerful decision support tool. Its full application would consider not only surface water flows, but broader ecosystem flows (e.g. considering managing evapotranspiration, soil moisture and groundwater, as per Figure 2.10), and as a

FIGURE 2.10

A simplified conceptual framework illustrating the role of ecosystems in the water cycle



Note: The figure lists in blue some of the water-related ecosystem services provided and underpinned. In reality the various services illustrated, and others, are more dispersed, interconnected and impacted by land and water-use activities (not shown in full).
Source: Adapted from MRC (2003).

quantitative tool to assist more holistic approaches within integrated water resources management (IWRM).

One of the biggest historical failings of water management has been to base allocations on demand as driven by 'sectors', and a worse failing, in many cases, has been to disregard the sustainable supply. Unsurprisingly, this has led to conflict, crisis, overuse and environmental degradation. But approaches are evolving, and the role of the ecosystem in sustaining water supply is becoming increasingly recognized. Furthermore, as described further in Section 8.3, a new paradigm is emerging, which shifts understanding of the 'ecosystem' (environment) as an unfortunate but necessary cost of development to an integral part of development solutions.

Ecosystems are increasingly seen as solutions to water problems, not just as a casualty. The change in perception of ecosystems as just another 'demand' sector is the result of increasing recognition of the services they deliver, their value and an increasing willingness, if not necessity, to sustain them. In practice, this has inevitably led to ever increasing 'competition' between, and debate about, the needs of sectors and 'the ecosystem'. But this is a welcome and positive trend as it also reflects improvement in dialogue and a step towards better-integrated water resources management, and therefore more sustainable development.

BOX 2.4

Rethinking ecosystem water 'demand' using an ecosystem services framework: Disaster risk transfer and mitigation in the Mississippi Delta, USA

River deltas are dynamic and complex ecosystems driven largely by hydrology, including the regular transfer of sediments and nutrients from the catchment into lowlands and the estuary. Their functioning underpins numerous ecosystem services, in particular land regulation and formation. This in turn delivers benefits through the maintenance of coastal stability and erosion regulation, thereby, for example, reducing disaster vulnerability. The Mississippi River Delta, in common with many rivers, has been highly modified: its hydrology has been changed through water abstraction, principally for agriculture, while reservoir construction, also for hydropower, has interrupted sediment transfer. The resulting degradation of associated wetlands services is becoming regarded by some as a major contributing factor to the scale of economic and human losses resulting from hurricanes. If treated as an economic asset, the delta's minimum asset value would be US$330 billion to US$1.3 trillion (at 2007 values) in terms of hurricane and flood protection, water supply, water quality, recreation and fisheries. Rehabilitation and restoration of this natural infrastructure would have an estimated net benefit of US$62 billion annually. This includes reduced disaster risk vulnerability and savings in capital and operational costs for physical infrastructure-based solutions (factoring in the economic costs on existing users of reallocating water use).

Agriculture has been a key driver of water allocation policy. Yet the value of food, fibre and feed produced by agriculture represents only a fraction of the multitude of other services provided by the ecosystem, particularly wetlands. Historically, water development policy for the Mississippi has effectively traded increased agricultural production for other ecosystem services in the delta, and with significant net overall economic loss when viewed holistically. In the context of uncertainty and risk, history shows that the reduction of risks to agriculture (i.e. more stable crop water supply) resulted in the transfer and amplification of risks downstream, amply demonstrated by the impact of hurricane Katrina on New Orleans in 2005.

Source: Batker et al. (2010).

BOX 2.5

The Mekong River Basin, South-East Asia

The Mekong River Agreement, signed in 1995 between Cambodia, Lao PDR, Thailand and Viet Nam, established the Mekong River Commission, and specifically requires minimum stream flows 'of not less than the acceptable minimum monthly natural flow during each month of the dry season' (Mekong River Agreement 1995, Article 6, point A). An Integrated Basin Flow Management Programme has been undertaken since 2004 to support discussions between the governments on sustainable development and reasonable and equitable transboundary sharing of beneficial uses. The process essentially involves assessment of ecosystem services and the relationships between them as illuminated by environmental flows, consideration of water 'demand' as required to achieve agreed multiple uses, and recognition and agreement on relevant trade-offs.

Note: For further information, see MRC (2011). For further information about environmental flows, including 22 different case studies, see Le Quesne et al. (2010).
The text cited in the box is drawn from the Mekong River Agreement, signed by the four countries in 1995. The agreement can be found here: http://www.mrcmekong.org/assets/Publications/agreements/agreement-Apr95.pdf

Notes

1 For detailed reports concerning the coverage of water supply and sanitation services and progress towards the Millennium Development Goal (MDG) relating to drinking water and sanitation (MDG 7, Target 7c), see the latest reports from the Joint Monitoring Programme (JMP) for Water Supply and Sanitation (WHO/UNICEF) at http://www.wssinfo.org and the Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) (UN-Water/WHO) at http://www.who.int/water_sanitation_health/glaas.

2 South Africa has now been added to this list and the present abbreviation is BRICS (not BRIC). However, the earlier designation is used in this passage because the statistical information here does not include South Africa.

3 IEA (2006) states that, taking into account very rapid technological progress, the higher figure could be 26,200 million tonnes of oil equivalent instead of 12,000. However, IEA also indicates that a more realistic assessment based on slower yield improvements would be 6,000–12,000. A mid-range estimate of around 9,500 would require about one-fifth of the world's agricultural land to be dedicated to biomass production.

4 The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal is the most comprehensive global environmental agreement on hazardous and other wastes. The Convention has 175 Parties and aims to protect human health and the environment against the adverse effects resulting from the generation, management, transboundary movements and disposal of hazardous and other wastes. The Basel Convention came into force in 1992.

5 The ecological or social impact of a water footprint obviously depends not only on the volume of water use, but also on where and when the water is used.

6 The cradle-to-cradle approach is based on a life-cycle or ecosystem view that aims not just to reduce the negative impacts of industry and growth, but to create equal or positive environmental and social footprints. Cradle-to-cradle products are designed to be completely waste-free, using renewable sources of energy in their production and ensuring water and energy efficiency in their use.

References

ADB (Asian Development Bank). 2010. *Ho Chi Minh City: Adaptation to Climate Change.* Mandaluyong City, Philippines, ADB. http://www.adb.org/documents/reports/hcmc-climate-change/hcmc-climate-change-summary.pdf

AFF (Australian Government Department of Agriculture, Fisheries and Forestry). 2002. *Introduction to Desalination Technologies in Australia.* Canberra, AFF. http://www.environment.gov.au/water/publications/urban/pubs/desalination-summary.pdf (Accessed 2 May 2011.)

Applebaum, B. 2000. *Water and Sustainability, Vol. 4: US Electricity Consumption for Water Supply and Treatment – The Next Half Century.* Report 1006787. Palo Alto, CA, Electric Power Research Institute (EPRI). http://dc213.4shared.com/doc/BJ17AQaE/preview.html

AquaFed. 2010. *Access to Drinking Water is Deteriorating in the Urban Half of the World.* Press release issued 6 September 2010. Stockholm, AquaFed. http://www.aquafed.org/pdf/AquaFed_UrbanTrends_PressRelease_Stockholm_EN_Pd_2010-09-07.pdf

ASCE (American Society of Civil Engineers). 2009. *Drinking Water. 2009 Report Card for America's Infrastructure.* Reston, Va., ASCE. http://www.infrastructurereportcard.org/fact-sheet/drinking-water

Batker, D., de la Torre, I., Costanza, R., Swedeen, P., Day, J., Boumans, R. and Bagstad, K. 2010. *Gaining Ground – Wetlands, Hurricanes and the Economy: The Value of Restoring the Mississippi River Delta.* Tacoma, Washington DC, Earth Economics. http://www.eartheconomics.org/Page12.aspx

Bauer, C. J. 1998. *Against the Current: Privatization, Water Markets, and the State in Chile.* Dordrecht, The Netherlands, Kluwer Academic Publishers.

Bruinsma, J. 2009. *The Resource Outlook to 2050: By How Much do Land, Water and Crop Yields Need to Increase by 2050?* Prepared for the FAO Expert Meeting on 'How to Feed the World in 2050', 24–26 June 2009, Rome.

BSR (Business for Social Responsibility) and Pacific Institute. 2007. *At the Crest of a Wave: A Proactive Approach to Corporate Water Strategy* San Francisco/Oakland, BSR/The Pacific Institute.

Comprehensive Assessment of Water Management in Agriculture. 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture.* London/Colombo, Earthscan/International Water Management Institute.

Cardinale, B. J. 2011. Biodiversity improves water quality through niche partitioning. *Nature,* Vol. 472, pp. 86–9.

Carter, N. T. and Campbell, R. J. 2009. *Water Issues of Concentrating Solar Power (CSP) Electricity in the U.S. Southwest.* Washington DC, Congressional Research Service (CRS). http://www.circleofblue.org/waternews/wp-content/uploads/2010/08/Solar-Water-Use-Issues-in-Southwest.pdf. (Accessed 2 May 2011.)

CEC (California Energy Commission). 2005. *California's Water – Energy Relationship.* Prepared in Support of the 2005 Integrated Energy Policy Report Proceeding (04-IEPR-01E). Calif., US, CEC. http://www.energy.ca.gov/2005publications/CEC-700-2005-011/CEC-700-2005-011-SF.PDF

Center for Sustainable Systems. 2008. *US Wastewater Treatment Factsheet.* University of Michigan. http://css.snre.umich.edu/facts/factsheets.html (Accessed 9 March 2008.)

Chiramba, T. 2010. *Ecological Impacts of Urban Water.* A presentation for World Water Week in Stockholm, 5–11 September. Nairobi, UNEP.

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D. and Savelli, H. (eds). 2010. *Sick Water? The Central Role of Wastewater Management in Sustainable Development. A Rapid Response Assessment.* UN-Habitat/UNEP/GRID-Arendal.

CTBR (Clean Technology Business Review). 2011. *Lindsey Construction to Pay Civil Penalty for Clean Water Act Violations.* CBTR Website. 2 September 2011 http://waterwastemanagement.cleantechnology-business-review.com/news/lindsey-construction-to-pay-civil-penalty-for-clean-water-act-violations-020911

Davis, M. 2006. Slum ecology: inequity intensifies Earth's natural forces. *Orion,* March/April. http://www.orionmagazine.org/index.php/articles/article/167 (Accessed October 2009.)

DOE (US Department of Energy). 2006. *Energy Demands on Water Resources.* Report to Congress on the Interdependency of Energy and Water. Washington DC, US DOE. http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf (Accessed 30 April 2011.)

Ecosystem Services. 2011. Website. http://www.ecosystemservices.org.uk/ecoserv.htm

EIA (US Energy Information Administration). 2010. *International Energy Outlook 2010: Highlights.* Washington DC, Office of Integrated Analysis and Forecasting, EIA, US Department of Energy. http://www.eia.gov/oiaf/archive/ieo10/highlights.html (Accessed 3 November 2011.)

EPA (US Environmental Protection Agency). 2006. *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990–2020.* Washington DC, EPA.

EPRI (Electric Power Research Institute). 2002. *Water and Sustainability (Volume 4): U.S. Electricity Consumption for Water Supply and Treatment – The Next Half Century.* Palo Alto, Calif., EPRI. http://www.circleofblue.org/waternews/wp-content/uploads/2010/08/EPRI-Volume-4.pdf (Accessed 2 May 2011.)

ETC Urban Agriculture. 2011. Website. Leusden, The Netherlands. http://www.etc-urbanagriculture.org/

Excellent. 2011. *Sand Dams.* Online article. Brentford, UK. http://www.excellentdevelopment.com/dams.php (Accessed 7 May 2011.)

FAO (Food and Agriculture Organization of the United Nations). 2006. *World Agriculture: Towards 2030/2050 – Interim Report – Prospects for Food, Nutrition, Agriculture and Majority Commodity Groups.* Rome, FAO.

––––. A. Wood and G. E. van Halsema (eds). 2008. *Scoping Agriculture-Wetland Interactions: Towards a Sustainable Multiple-Response Strategy.* FAO Water Reports 33. Rome, FAO.

––––. 2009. *The State of Food Insecurity in the World (SOFI) 2009: Economic Crises – Impacts and Lessons Learned.* Rome, FAO.

––––. 2011*a*. *The State of the World's Land and Water Resources: Managing Systems at Risk.* London, Earthscan.

––––. 2011*b*. *Climate Change, Water and Food Security.* FAO Water Report 36. Rome, FAO.

––––. 2011*c*. AQUASTAT online database. Rome, FAO. http://www.fao.org/nr/water/aquastat/data/query/index.html

Foster, S. S. D., Lawrence, A. R. and Morris, B. L. 1997. *Groundwater in Urban Development: Assessing Management Needs and Formulating Policy Strategies.* World Bank Technical Paper 390. Washington DC, The World Bank.

Galloway, J. N., Burke, M., Bradford, G. E., Naylor, R., Falcon, W., Chapagain, A. K., Gaskell, J. C., McCullough, E., Mooney, H. A., Oleson, K. L. L., Steinfeld, H., Wassenaar, T. and Smil, V. 2007. International trade in meat: the tip of the pork chop. *Ambio,* Vol. 36, No. 8, pp. 622-9.

Garrido-Lecca, H. 2010. *Inversión en agua y saneamiento como respuesta a la exclusión en el Perú: gestación, puesta en marcha y lecciones del Programa Agua para Todos (PAPT).* LC/W.313. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/4/41044/lcw313e.pdf

Gascoyne, C. and Aik, A. 2011. *Unconventional Gas and Implications for the LNG Market.* Global Facts Energy. Jakarta, Pacific Energy Summit. http://www.nbr.org/downloads/pdfs/eta/PES_2011_Facts_Global_Energy.pdf (Accessed 30 April 2011.)

Gerbens-Leenes P. W., Hoekstra, A. Y. and Van der Meer, Th. 2008. *Water Footprint of Bio-Energy and Other Primary Energy Carriers.* Value of Water Research Report Series No. 29. Delft/Enschede, The Netherlands, UNESCO-IHE Institute for Water Education/Delft University of Technology/University of Twente. http://www.waterfootprint.org/Reports/Report29-WaterFootprintBioenergy.pdf (Accessed 30 April 2011.)

Gleick, P. H. 1994. Water and energy. *Annual Review of Energy and Environment,* Vol. 19, pp. 267–99.

Grobicki, A. 2007. *The Future of Water Use in Industry.* Technical report for the UNIDO TF Summit. Technology Foresight Summit 2007, 27–29 September 2007, Budapest, Hungary, organized by UNIDO in cooperation with the Government of Hungary.

GVEP (Global Village Energy Partnership International). 2011. Website. London, GVEP. http://www.gvepinternational.org/en/community/products-services (Accessed 7 May 2011.)

Hoekstra, A. Y. and Chapagain, A. L. 2008. *Globalization of Water: Sharing the Planet's Freshwater Resources.* Oxford, UK, Blackwell Publishing.

Hovorka, A., de Zeeuw, H. and Njenga, M. (eds). 2009. *Women Feeding Cities – Mainstreaming Gender in Urban Agriculture and Food Security.* Warwickshire, UK, Practical Action Publishing.

Howard, G. and Bartram, J. 2003. *Domestic Water Quantity, Service Level and Health.* Geneva, WHO.

Huffaker, R., Whittlesey, N. K. and Wandschneider, P. R. 1993. Institutional feasibility of contingent water marketing to increase migratory flows for salmon on the upper Snake River. *Natural Resources Journal,* Vol. 33, No. 3, pp. 671–96.

ICOLD (International Commission on Large Dams). 2009. *World Register of Large Dams*. Paris, ICOLD.

IEA (International Energy Agency). 2006. World Energy Outlook 2006. Paris, IEA.

----. 2007. *World Energy Outlook 2007.* Paris, IEA.

IHA (International Hydropower Association). 2009. *IHA Statement on Evaporation from Hydropower Reservoirs.* London, IHA.

International Bank for Reconstruction and Development/ World Bank. 1994. *World Development Report 1994: Infrastructure for Development.* New York, Oxford University Press.

IPCC (Intergovernmental Panel on Climate Change). 2011. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN).* Prepared by Working Group III of the Intergovernmental Panel on Climate Change. Geneva, IPCC.

Jouravlev, A. 2004. *Drinking Water Supply and Sanitation Services on the Threshold of the XXI Century.* LC/L.2169-P. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.eclac.cl/publicaciones/xml/9/19539/lcl2169i.pdf

Le Quesne, T., Kendy, E. and Weston, D. 2010. *The Implementation Challenge: Taking Stock of Government Policies to Protect and Restore Environmental Flows.* Washington DC, The Nature Conservancy/Worldwide Fund for Nature (WWF).

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

Lundqvist, J. 2010. Producing more or wasting less. Bracing the food security challenge of unpredictable rainfall. L. Martínez-Cortina, G. Garrido and L. López-Gunn, L. (eds) *Re-thinking Water and Food Security: Fourth Marcelino Botín Foundation Water Workshop.* London, Taylor & Francis Group.

Lundqvist, J., de Fraiture, C. and Molden, D. 2008. *Saving Water: From Field to Fork – Curbing Losses and Wastage in the Food Chain.* Policy Brief. Stockholm, Stockholm International Water Institute (SIWI).

MA (Millennium Ecosystem Assessment). 2005. Fresh water ecosystem services. *Ecosystems and Human Well-being: Synthesis.* Washington DC, Island Press, pp. 213–255.

Mann, H. and Smaller, C. 2010. Foreign land purchases for agriculture: What impact on sustainable development? *Sustainable Development Innovation Briefs,* Issue 8. http://www.un.org/esa/dsd/resources/res_pdfs/publications/ib/no8.pdf

Mays, L. (ed.). 2009. *Integrated Urban Water Management: Arid and Semi-Arid Regions. Urban Water Series.* Paris/ London, UNESCO-IHP, Taylor & Francis.

MRC (Mekong River Commission for Sustainable Development). 2011. *The Mekong River Commission.* Website. http://www.mrcmekong.org

----. 2003. *Mekong River Awareness Kit.* Website. Phnom Penh/Vientiane, MRC. http://ns1.mrcmekong.org/RAK/html/rak_frameset.html

Mwanza, D. 2005. Promoting good governance through regulatory frameworks in African water utilities. *Water Sci. Technol.,* Vol. 51, No. 8, pp. 71–79.

NETL (National Energy Technology Laboratory). 2009. *Use of Non-Traditional Water for Power Plant Applications: An Overview of DOE/NETL R&D Efforts.* Pittsburgh, Pa., NETL.

NRDC (Natural Resources Defense Council). n.d. What's on Tap? Website. New York, NRDC. http://www.nrdc.org/water/drinking/uscities/contents.asp

NWC (National Water Commission). 2011. U*rban Water in Australia: Future Directions.* Canberra, NWC. http://www.nwc.gov.au/resources/documents/Future_directions.pdf

Olson, E. 2003. *What's on Tap? Grading Drinking Water in U.S. Cities.* New York, Natural Resources Defense Council (NRDC). http://www.nrdc.org/water/drinking/uscities/pdf/whatsontap.pdf

Øvergaard, S. 2008. *Issue Paper: Definition of Primary and Secondary Energy.* Prepared as input to Chapter 3: Standard International Energy Classification (SIEC) in the International recommendation on Energy Statistics (IRES). Oslo, Division of Energy Statistics, Statistics Norway. http://unstats.un.org/unsd/envaccounting/londongroup/meeting13/LG13_12a.pdf (Accessed 30 April 2011.)

Payne, J. G. 2007. *Matching Water Quality to Use Requirements.* Technical Report for UNIDO Technology Foresight Summit 2007, 27–29 September 2007, Budapest.

Pegasys. 2011. *Conceptual Framework for Assessing Water Use in Energy Generation with a focus on Hydropower.* Cape Town, Pegasys.

Pickering de la Fuente, G. 2011. El hito ambiental de 2012. *Newsletter ANDESS,* No. 25. Santiago, Asociación Nacional de Empresas de Servicios Sanitarios (ANDESS). http://www.andess.cl/news/News25/nota1.html

SABMiller Plc and WWF-UK. 2009. *Water Footprinting: Identifying and Addressing Water Risks in the Value Chain.* Technical report. Woking/Surrey, UK, SABMiller Plc/World Wide Fund for Nature UK.

Scanlon, B. R., Jolly, I., Sophocleous, M. and Zhang, L. 2007. Global impacts of conversions from natural to agricultural ecosystems on water resources: quantity versus quality. *Water Resources Research,* Vol. 43, W03437.

Sclar, E. D., Garau, P. and Carolini, G. 2005. The 21st century health challenge of slums and cities. *The Lancet,* Vol. 365, pp. 901–903.

Sieger, R. B. and Whitlock D. 2005. Session for the *CHP and Bioenergy for Landfills and Wastewater Treatment Plants* workshop, Salt Lake City, UT, 11 August 2005. http://www.docstoc.com/docs/22892252/CHP-and-Bioenergy-for-Landfills-and-Wastewater-Treatment-Plants

SISS (Superintendencia de Servicios Sanitarios). 2011. *Informe de Gestión del Sector Sanitario 2010.* Santiago, SISS. http://www.siss.gob.cl/577/articles-8333_recurso_1.pdf

Smit, J., Ratta, A. and Nasr, J. 1996. *Urban Agriculture: Food, Jobs, and Sustainable Cities.* New York, United Nations Development Programme (UNDP).

Stecko, S. and Barber, N. 2007. *Exposing Vulnerabilities: Monsoon Floods in Mumbai, India.* Unpublished case study prepared for the Global Report on Human Settlements 2007.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. and de Haan, C. 2006. *Livestock's Long Shadow: Environmental Issues and Options.* Rome, FAO/LEAD. ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e.pdf

Stillwell A. S. 2010. Energy Water Nexus in Texas, Master's Thesis, University of Texas at Austin.

Stillwell, A. S., King, C. W. and Webber, M. E. 2010. Desalination and long-haul water transfer as a water supply for Dallas, Texas: A case study of the energy-water nexus in Texas. *Texas Water Journal,* Vol. 1, No. 1, pp. 33–41.

Stillwell, A. S., King, C. W., Webber, M. E., Duncan, I. J. and Hardberger, A. 2011. The energy-water nexus in Texas. *Ecology and Society* (Special Feature: The Energy-Water Nexus: Managing the Links between Energy and Water for a Sustainable Future), Vol. 16, No. 1, p. 2.

Strokes, J.R. and Horvath, A. 2009. Energy and air emission effects of water supply. *Environmental Science and Technology,* Vol. 43, No. 8, pp. 2680–7.

TEEB (The Economics of Ecosystems and Biodiversity), 2009. *TEEB Climate Issues Update.* Geneva, United Nations Environment Programme (UNEP). http://www.teebweb.org/InformationMaterial/TEEBReports/tabid/1278/language/en-US/Default.aspx

Tucci, C., Goldenfum, J. A. and Parkinson, J. N. (eds). 2010. *Integrated Urban Water Management: Humid Tropics.* IHP Urban Water Series. Paris/Boca Raton, Fla., UNESCO-IHP, CRC Press.

Twomey, K. M. and Webber, M. E. 2011. Evaluating the energy intensity of the US public water system. *Proceedings of the 5th International Conference on Energy Sustainability.* Washington DC, American Society of Mechanical Engineers (ASME).

UNDESA (United Nations Department of Economic and Social Affairs, Population Division). 2009. *World Population Prospects: The 2008 Revision, Highlights,* Working Paper No. ESA/P/WP.210. New York, UN.

UNEP (United Nations Environment Programme). 2007. *Global Environment Outlook 4.* Nairobi, UNEP.

––––. 2010. *UNEP Yearbook: New Science and Developments in Our Changing Environment.* Nairobi, UNEP.

UNEP/GRID-Arendal. 2008. *Vital Water Graphics. An Overview of the State of the World's Fresh and Marine Waters* (2nd edn). Nairobi, UNEP. http://www.unep.org/dewa/vitalwater/article48.html

UN-Habitat (United Nations Human Settlements Programme). 2003. *The Challenge of Slums: Global Report on Human Settlements.* Nairobi, UN-Habitat.

––––. 2006. *Meeting Development Goals in Small Urban Centres: Water and Sanitation in the World's Cities.* Nairobi/London, UN-Habitat/Earthscan.

––––. 2010. *The State of the World's Cities 2010/2011: Cities for All: Bridging the Urban Divide.* Nairobi, UN-Habitat.

United Nations (under the coordination of A. Bárcena, A. Prado and A. León). 2010. *Achieving the Millennium Development Goals with Equality in Latin America and the Caribbean: Progress and Challenges.* LC/G.2460, Santiago, United Nations Publications. http://www.eclac.cl/publicaciones/xml/5/39995/portada-indice-intro-en.pdf

Vahala, R. 2004. European Vision for Water Supply and Sanitation in 2030. *Water Supply and Sanitation Technology Platform.*

Vairavamoorthy, K. 2008. *Cities of the Future and Urban Water Management.* Paper presented on 27 June 2008 during Thematic Week 2 of the Zaragoza International Exhibition, 2008.

Vollaard, A. M., Ali, S., van Asten, H. A. G. H., Widjaja, S., Visser, L. G., Surjadi, C. and van Dissel, J. T. 2004. Risk factors for typhoid and paratyphoid fever in Jakarta, Indonesia. *J. Am. Med. Assoc.,* Vol. 291, pp. 2607–2615.

WEC (World Energy Council). 2010. *Water for Energy.* London, WEC. http://www.worldenergy.org/documents/water_energy_1.pdf

WEF (World Economic Forum). 2009. *Energy Vision Update 2009: Thirsty Energy: Water and Energy in the 21st Century.* Geneva/Englewood, Colo., WEF/Cambridge Energy Research Associates. http://www.weforum.org/reports/thirsty-energy-water-and-energy-21st-century?fo=1 (Accessed 30 April 2011.)

––––. 2011. *Water Security: the Water-Food-Energy-Climate Nexus: the World Economic Forum initiative.* Washington DC, Island Press.

WEF (Water Environment Federation). 1997. *Energy Conservation in Wastewater Treatment Facilities Manual of Practice.* Alexandria, VA, WEF.

WHO/UNICEF. 2006. *Meeting the MDG Drinking Water and Sanitation Target: the Urban and Rural Challenge of the Decade.* Geneva/New York, WHO/UNICEF. http://www.who.int/water_sanitation_health/monitoring/jmpfinal.pdf

––––. 2010. Joint Monitoring Programme for Water Supply and Sanitation. *Progress on Sanitation and Drinking-Water: 2010 Update.* Geneva/New York, WHO/UNICEF.

Wild, D., Francke, C-J., Menzli, P. and Schön, U. 2010. *Water: A Market of the Future.* A Sustainable Asset Management (SAM) Study. Switzerland, SAM.

WWF (World Wide Fund for Nature). 2011. T*he Energy Report. 100% Renewable Energy by 2050.* Gland, Switzerland, WWF. http://wwf.panda.org/what_we_do/footprint/climate_carbon_energy/energy_solutions/renewable_energy/sustainable_energy_report/ (Accessed 2 May 2011).

WWAP (World Water Assessment Programme). 2009. *United Nations World Water Development Report 3: Water in a Changing World.* Paris/London, UNESCO Publishing/Earthscan.

Zimmer, D. and Renault, D. n.d. *Virtual Water in Food Production and Global Trade: Review of Methodological Iissues and Preliminary Results.* FAO, Rome.

CHAPTER 3

The water resource: Variability, vulnerability and uncertainty

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Past editions of the *World Water Development Report* (WWDR) have addressed the state of the world's water resources in different but complementary ways. WWDR1 reported on long-term averages and general patterns of water availability through different elements of the hydrological cycle at the global scale. WWDR2 added a greater focus to the dimension of 'variability' in the distribution of water resources over space and through time, also describing some of the main human impacts in terms of the quantity and quality of the resource. WWDR3 explored the relationship between the water cycle and other global biogeochemical cycles, observational evidence of the impacts of climate change on the water cycle, and the need for increased observation and monitoring.

This chapter builds on the information provided in previous WWDR editions, focusing now on specific elements that had not received detailed coverage in the series. In an effort to better understand variability in the resource and the origins of the related uncertainties, this chapter opens with a description of the external stressors on water resources as sources of uncertainty in the hydrological cycle, including the complex, inter-related ensemble of dynamic natural processes, such as the El Niño-Southern Oscillation, which scientists refer to as 'climate forcings'. The chapter then focuses on long-term natural storage via two specific but often overlooked or misunderstood elements of the hydrological cycle – groundwater and glaciers – in terms of their benefits and vulnerabilities. The chapter concludes with a section describing how water quality and quantity are inextricably linked key elements of water availability, adding yet another layer of uncertainty and complexity to understanding and addressing water supply and availability issues.

With the exception of the subsection on glaciers, which is original to Part 1, the material in this chapter has been condensed from the challenge area reports (Part 3/Volume 2) 'State of the resource: Quantity' (Chapter 15) and 'State of the resource: Quality' (Chapter 16) as well as the special report on Groundwater (Chapter 36).

3.1 The hydrological cycle, external stressors on water resources, and sources of uncertainty

Precipitation delivers water unevenly over the planet from one year to the next. There can be considerable variability between arid and humid climates and wet and dry seasons. As a result, distribution of freshwater supplies can be erratic with different countries and regions receiving different quantities of water over any given year.

The average total annual renewable water resources (TARWR) available to each country (Figure 3.1) provides an overview of this geographical variability. Clearly, some countries have more water than others. However, such a measure is imprecise since a country's size can significantly influence much of the variation between different countries. It is often therefore more useful to consider the total water available per person (Figure 3.2), which can provide a more appropriate indication of water availability for social or economic purposes.[1] It should be noted, however, that tropical countries in Asia and Africa with the highest populations have low availability of freshwater. This poses a serious challenge to future water resources development and management (see Chapter 4, Section 4.6.1).

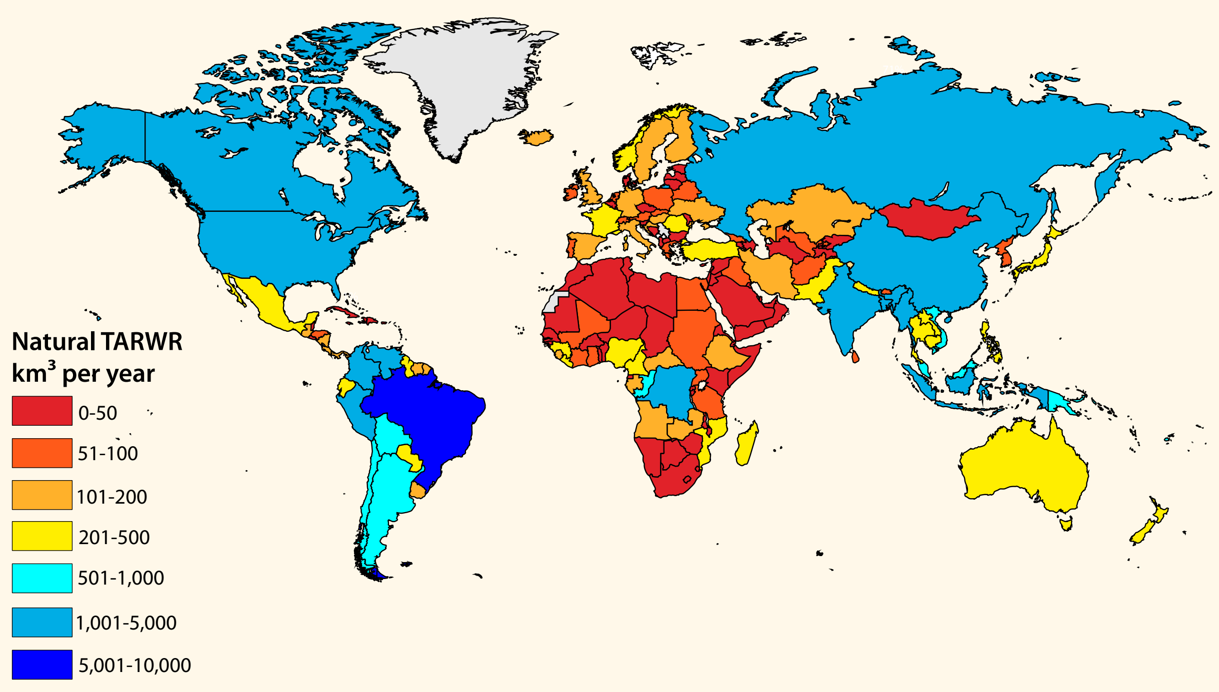
Understanding the spatial and temporal distribution and movement of water is crucial for efficient water resources management. Water resource management plans and policies must take into account this variability and distribution of freshwater supplies.

The hydrological cycle is driven by a complex, interrelated ensemble of dynamic natural processes, which scientists refer to as 'climate forcings'. The Earth's tilt and rotation around the Sun are among the primary drivers of seasonal variations in precipitation and water availability. Atmospheric and oceanic circulation patterns and their interactions are equally important drivers of weather, climate and the hydrological cycle. A better understanding of these phenomena (e.g. the El Niño-Southern Oscillation) and the 'teleconnections'[2] among different drivers can enhance predictive capability in many regions.

Humans are in the process of altering the earth's climate and by inference the global patterns in the circulation of moisture. Significant control over this part of

FIGURE 3.1

Total annual renewable water resources (TARWR) by country – most recent estimates (1985–2010)



Source: FAO AQUASTAT database (http://www.fao.org/nr/aquastat, accessed in 2011).

the hydrological cycle is not possible, but humans do have a significant impact on other components of the cycle. Some interventions are deliberate, such as modifying runoff through storage and inter-basin transfers. The former impacts floods and droughts to ensure water is available *when* needed and damage is averted or minimized when there is an excess; the latter brings water to *where* it is needed. Other interventions such as changing land surfaces for urban settlements or agriculture can severely alter the hydrological cycle through changes in infiltration, runoff and evapotranspiration rates.

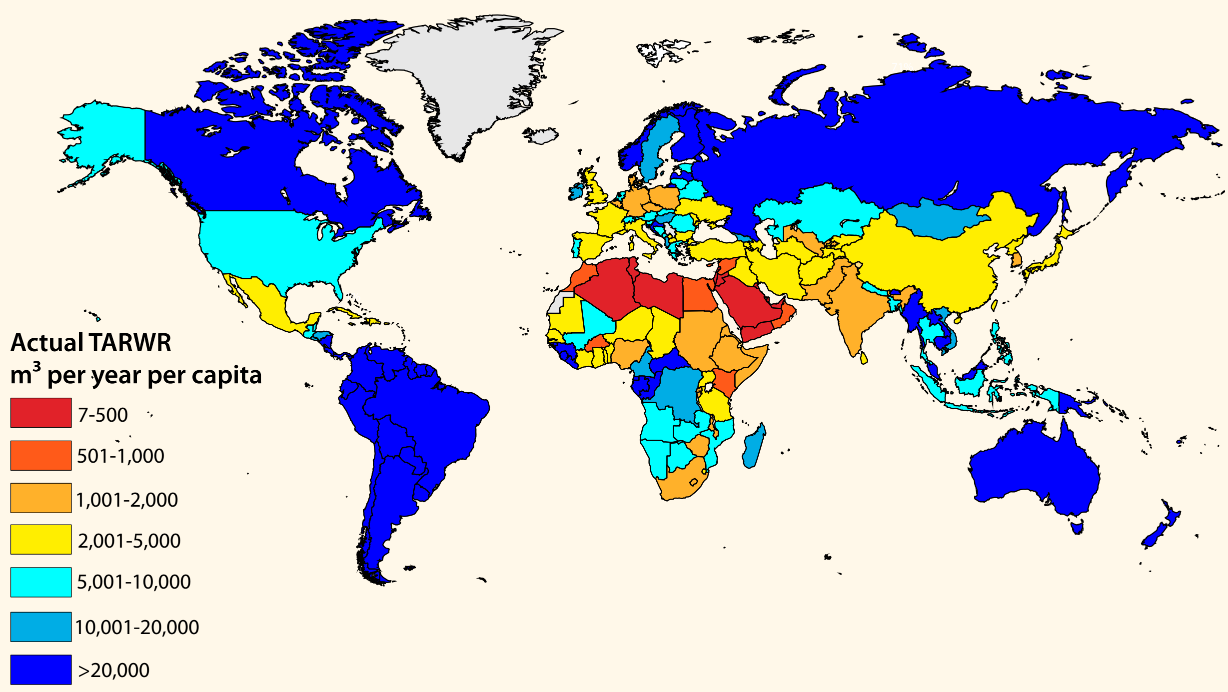
The state of water resources is one of constant change, resulting from the natural variability of the earth's climate system and the anthropogenic alteration of that system and the land surface through which the hydrological cycle is modulated. Specific changes to water resources and the hydrological cycle include:

- Changes in mean surface flows due to natural climate variability at interannual and multidecadal time scales and climate change
- Increased flood potential due to climate change
- Increased losses due to temperature increase
- Changes in the seasonality (or timing) of flows, especially in snow melt basins
- Changes in flows from glaciers due to their retreat
- Decreasing snow and permafrost
- Groundwater depletion – losing the buffer against rainfall variability
- Changes in soil moisture

The state of water resources is also influenced by withdrawals to meet socio-economic demands. These are in turn influenced by population growth, economic development and dietary changes, as well as by control measures exerted to protect settlements in flood plains and drought-prone regions. These change forces and possible developments are described in Chapter 9. These sources of change and the interactions between them create a new level of uncertainty associated with the use and availability of water resources – in addition to existing uncertainties related to the earth's climate system and hydrological cycle. As a result, it is no longer possible to assume that the future hydrological record will follow the course of the historical record.

FIGURE 3.2

Per capita total annual renewable water resources (TARWR) by country – population data from 2009



Source: FAO AQUASTAT database (http://www.fao.org/nr/aquastat, accessed in 2011).

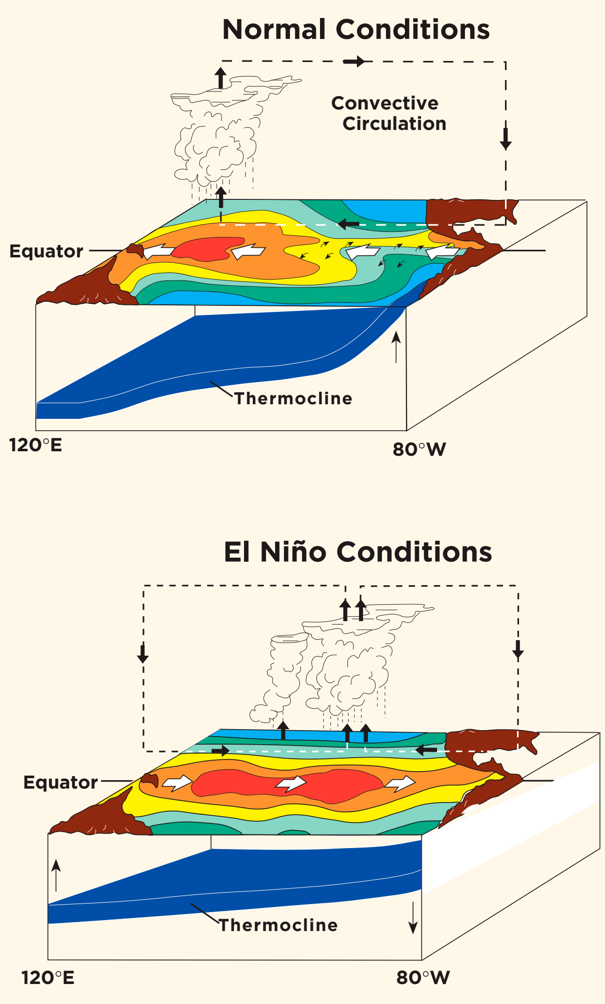
3.1.1 Drivers of global climate and hydrological variability

Water movement on spatial and temporal scales over the globe plays a crucial role in creating areas of abundance and scarcity. It is increasingly evident that a few large-scale climate drivers orchestrate this movement: the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO). Increased understanding of these drivers has led to their use in interannual predictions of hydrology and climate and efficient resource planning. The following sections briefly describe ENSO, PDO and NAO.

> "It is no longer possible to assume that the future hydrological record will follow the course of the historical record."

FIGURE 3.3

Schematic of normal and El Niño conditions in the tropical Pacific Ocean



Source: NOAA/PMEL/TAO (n.d.).

ENSO

The El Niño-Southern Oscillation is a coupled ocean-atmospheric phenomenon in the tropical Pacific Ocean and the dominant driver of global climate at seasonal to interannual time scales. Warm waters in the equatorial western Pacific Ocean shift to the central and eastern region periodically over a three to eight-year time scale (Figure 3.3). As an immediate consequence, tropical western Pacific regions and Northern Australian regions see a reduction in rainfall and tropical eastern parts of South America see an increase in rainfall. These convection changes in the tropical Pacific trigger teleconnection responses to other parts of the world (Figure 3.4), especially South and South-East Asia and Africa. These changes also impact the location and strength of the mid-latitude jet stream and consequently the weather over North America. There has been extensive documentation of ENSO impacts on precipitation, temperature, hurricanes and tropical cyclones, ecosystems, agriculture, water resources and public health around the world, especially from the tropical countries where most of the world's population reside. Figures 3.4, 3.5 and 3.6 show the ENSO schematic, global teleconnections and mid-latitude jet stream shifts.

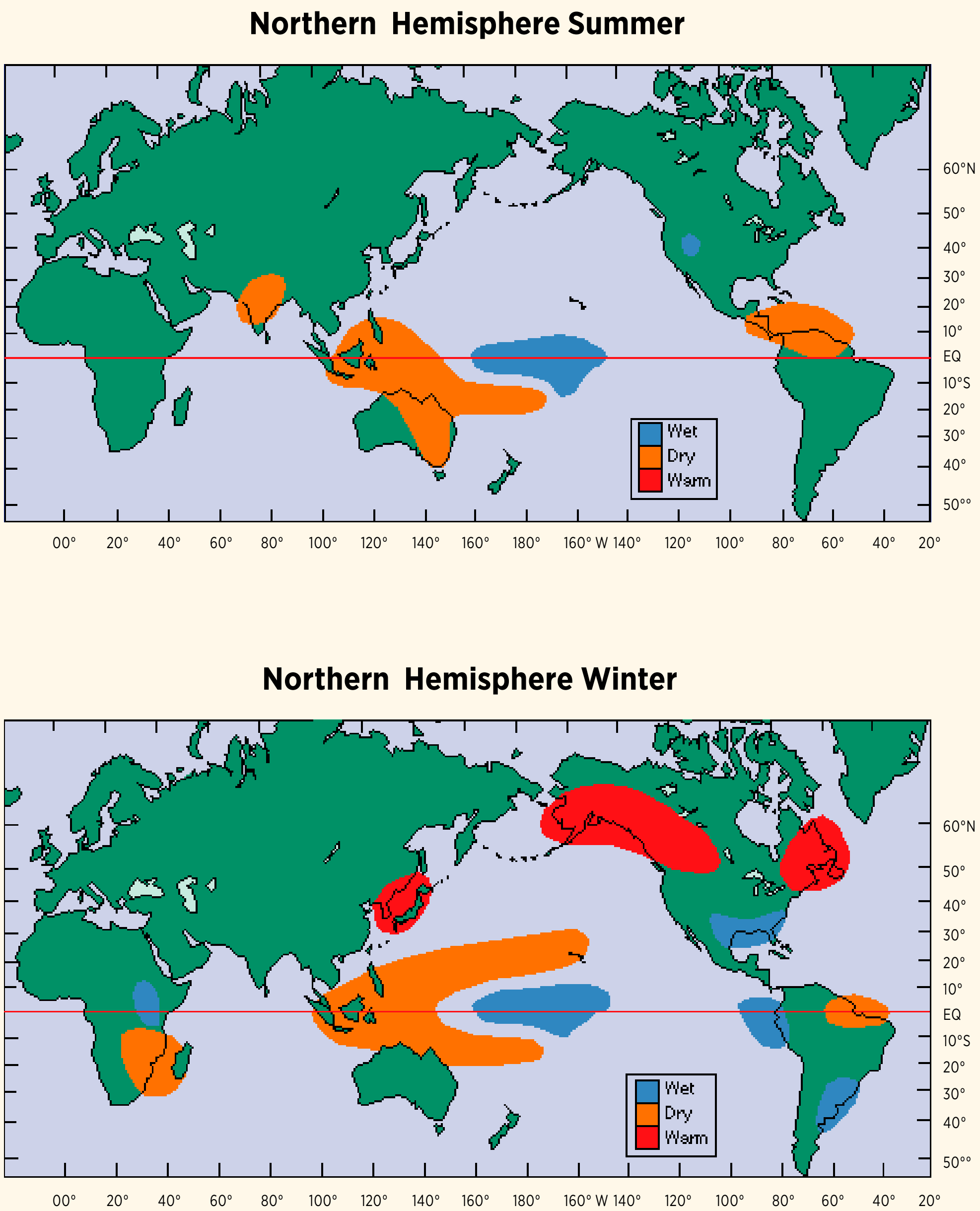
Understanding the ENSO teleconnections alone can provide significant predictive capability in many places. These efforts have received a significant boost since the mid-1990s with ongoing observation of the tropical Pacific Ocean, which has led to skilful long-lead ENSO predictions of immense value to society. The National Oceanic and Atmospheric Administration (NOAA) has created a dedicated site on El Niño[3] that provides information on ENSO monitoring and prediction efforts, and compiles links on impacts as well as numerous references.

PDO

The Pacific Decadal Oscillation is manifested in the large-scale sea surface temperature pattern predominant in the Northern Pacific region, but also includes participation from the tropical Pacific. The pattern resembles that of ENSO, but is slightly broader; furthermore, its index demonstrates a distinct variability over a decadal timescale. PDO has been shown to impact fisheries in the north-western United States of America (USA), and there is a growing body of literature that identifies its impacts on hydrology and extreme events such as droughts, focusing in particular on the same region. Figure 3.4 shows the spatial

FIGURE 3.4

Impacts of El Niño on global climate during northern hemisphere summer and winter seasons



Note: The La Niña impacts are quite symmetric. Notice that ENSO impacts rainfall and temperature especially in the developing countries in the tropics.
Source: NOAA/PMEL/TAO (n.d.).

pattern and time series of this phenomena. The Joint Institute for the Study of the Atmosphere and Ocean (JISAO) has a site that provides substantial details on PDO: data, impacts and bibliography.[4]

NAO

The North Atlantic Oscillation is a climate driver in the North Atlantic region and functions as an atmospheric feature mainly in the winter season. It is characterized by the location and strength of subtropical high-pressure and subpolar low-pressure centres in the North Atlantic (Figure 3.5). The location and strength of these pressure centres steer the jet stream and the storm tracks and consequently the regional climate and hydrology. The role of NAO in modulating European and North American climate has long been known, but the physical mechanism and its role in modulating sea surface temperatures are the subject of intense study. Recent studies have also identified NAO to be part of a hemispherical wide series of pressure centres named the Arctic Oscillation (AO). This has a decadal timescale of variability.[5]

Other drivers

Other climate drivers that that drive the global climate and hydrology at multi-decadal timescales are being studied. These include the Atlantic Multi Decadal Oscillation (AMO) and the Atlantic Meridional Overturning Circulation (AMOC) linked with the thermohaline circulation of which the Gulf Stream is an integral component.[6]

3.2 The vulnerability of natural long-term storage: Groundwater and glaciers

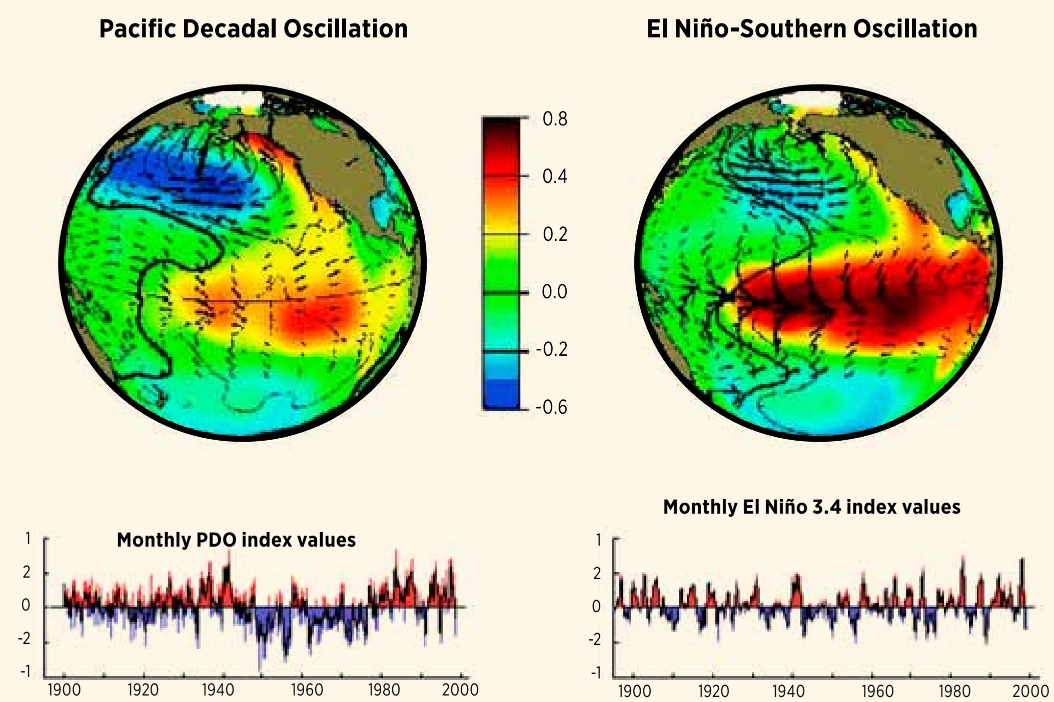
3.2.1 Groundwater: A resilient resource in transition

The changing role of groundwater in the world

Unlike surface water, which has been intensively developed in many parts of the world for thousands of years, groundwater has remained until less than a century ago a rather sparsely developed resource. However, during the twentieth century, an unprecedented 'silent revolution' (Llamas and Martínez-Santos, 2005) in groundwater abstraction took place across the globe. This boom was driven by population growth

FIGURE 3.5

Spatial pattern and time index of PDO and El Niño



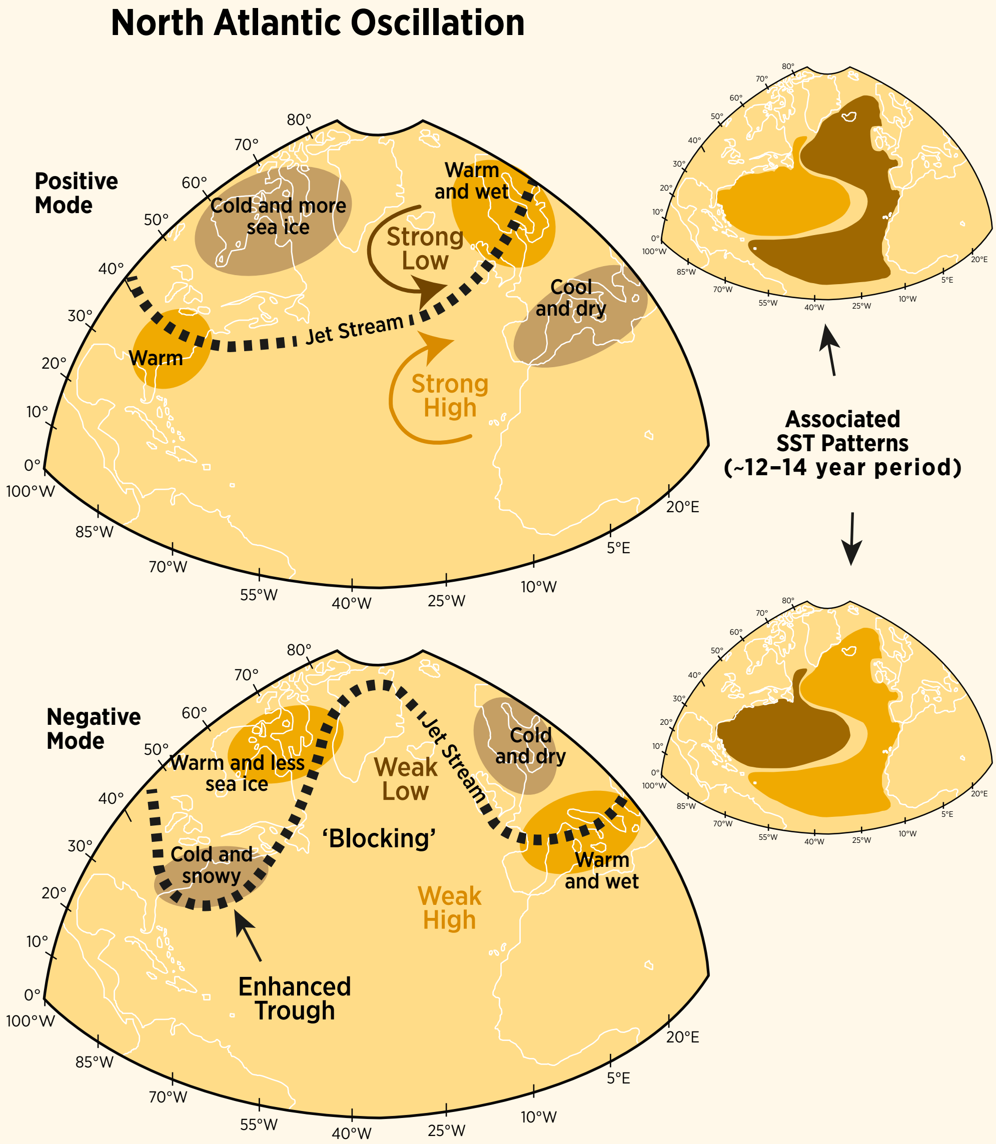
Source: JISAO (2000).

and the associated increasing demand for water, food and income, and facilitated by knowledge, technology and access to funding. Intensive groundwater abstraction began in the first half of the twentieth century in a limited number of countries including Italy, Mexico, Spain and the USA, and then expanded worldwide since the 1960s (Comprehensive Assessment of Water Management in Agriculture, 2007). This fundamentally changed the role of groundwater in human society, in particular in the irrigation sector where it triggered an 'agricultural groundwater revolution' (Giordano and Villholth, 2007), significantly boosting food production and rural development. The use of groundwater has also considerably modified local and global water cycles, environmental conditions and ecosystems.

As of 2010 the world's aggregated groundwater abstraction is estimated at approximately 1,000 km^3 per year – about 67% of which is used for irrigation, 22% for domestic purposes, and 11% for industrial purposes (AQUASTAT, 2011; EUROSTAT, 2011; IGRAC, 2010; Margat, 2008; Siebert et al., 2010).[7] Figure 3.7 shows

FIGURE 3.6

NAO spatial pattern and its impact on the mid-latitude jet stream and its impacts on climate over North America and Western Europe



Source: AIRMAP (n.d., fig.4) (J. Bradbury and C. Wake).

the global distribution of groundwater abstraction by the year 2000. Two-thirds of the total amount is abstracted in Asia with India, China, Pakistan, Iran and Bangladesh as major consumers (Tables 3.1 and 3.2). The global groundwater abstraction rate has at least tripled over the past 50 years and continues to increase at an annual rate of 1 to 2%. In a number of countries, however, abstraction rates have peaked and are now stable or even decreasing (Comprehensive Assessment of Water Management in Agriculture, 2007), as illustrated in Figure 3.8. These estimates may not be precise, but they suggest that the abstraction of groundwater accounts for approximately 26% of total global water withdrawal and equals around 8% of mean global groundwater recharge.

Groundwater is now a significant source of water for human consumption, supplying nearly half of all drinking water in the world (WWAP, 2009) and around 43% of all water effectively consumed in irrigation[8] (Siebert et al., 2010). Yet the relevance and socio-economic impacts of groundwater development are higher than these percentages may suggest. Due to the relatively large volumes of water stored underground, most aquifers have a considerable buffer capacity, which keeps their water available for withdrawal even during very long periods without rainfall. This enables people to have reliable access to water in regions that would otherwise be too dry if their water supply depended only on precipitation or surface water. The most striking example of this buffer capacity is formed by non-renewable groundwater resources: various large aquifer systems on earth still

TABLE 3.1

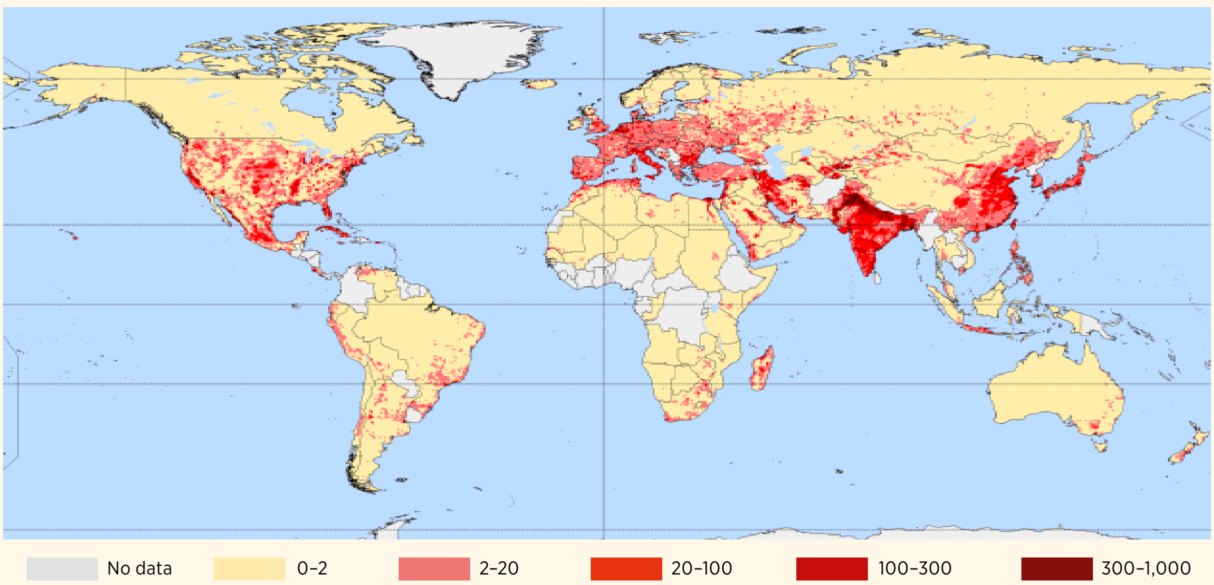
Top 10 groundwater-abstracting countries as of 2010

Country	Abstraction (km³/year)
1. India	251
2. China	112
3. United States of America	112
4. Pakistan	64
5. Iran	60
6. Bangladesh	35
7. Mexico	29
8. Saudi Arabia	23
9. Indonesia	14
10. Italy	14

Note: About 72% of the global groundwater abstraction takes place in these ten countries.
Source: Data from IGRAC (2010), AQUASTAT (2011) and EUROSTAT (2011).

FIGURE 3.7

Intensity of groundwater abstraction by the year 2000 (in mm per year), as allocated to 0.5° x 0.5° grid cells by the PCR-GLOBWB model



Source: Wada et al. (2010, p. 2, © American Geophysical Union, reproduced by permission).

contain very large volumes of groundwater in spite of not having received significant replenishment during recent millennia (Foster and Loucks, 2006). However, no matter how large the volumes of water contained in these aquifers may be, the fact that they are non-renewable means they can eventually be mined to exhaustion if their use is not managed properly. And there are hotspots where the availability of non-renewable groundwater resources has reached critical limits (see below).

Groundwater is crucial for the livelihoods and food security of 1.2 to 1.5 billion rural households in the poorer regions of Africa and Asia (Comprehensive Assessment of Water Management in Agriculture, 2007), but also for domestic supplies of a large part of the population elsewhere in the world. Furthermore, groundwater-fed irrigation is usually considerably less susceptible to water shortage risks than irrigation supplied by surface water. This is likely to result in higher economic returns per unit of water used, as demonstrated by studies in Spain (Llamas and Garrido, 2007) and India (Shah, 2007). Consequently, the share of groundwater in the overall socio-economic benefit from abstracted water tends to be higher than its volumetric share in the total water abstraction.

Significant changes in the state of groundwater systems
Inflows and outflows, the volume of water stored and related groundwater levels, and water quality, are key characteristics of the state of any groundwater system. Steadily increasing rates of groundwater abstraction and other human interactions with groundwater, such as those produced by changing land use and emission of polluting substances, all affect the state of groundwater systems. Climate change and water resources management measures also have an impact on the state of groundwater systems. As a result, the majority of the world's groundwater systems are no longer in dynamic equilibrium, but do show significant trends. In particular, reduction of natural outflows, decreasing stored volumes, declining water levels and water quality degradation are widely observed, along with changes in the mean rate of groundwater renewal.

The groundwater resources world map produced by WHYMAP (2008) provides a visual impression of the global geographic distribution of favourable versus less favourable groundwater zones in terms of hydraulic continuity, stored volume and rate of groundwater renewal (recharge). A large proportion of the earth's groundwater (probably 80 to 90%) is stored in the zones mapped as 'major groundwater basins', covering only around 35%

TABLE 3.2

Key estimates on global groundwater abstraction (reference year 2010)

Continent	Groundwater abstraction[1]					Compared to total water abstraction	
	Irrigation	Domestic	Industrial	Total		Total water abstraction[2]	Share of groundwater
	km³/year	km³/year	km³/year	km³/year	%	km³/year	%
North America	99	26	18	143	15	524	27
Central America and the Caribbean	5	7	2	14	1	149	9
South America	12	8	6	26	3	182	14
Europe (including Russian Federation)	23	37	16	76	8	497	15
Africa	27	15	2	44	4	196	23
Asia	497	116	63	676	68	2257	30
Oceania	4	2	1	7	1	26	25
World	666	212	108	986	100	3831	26

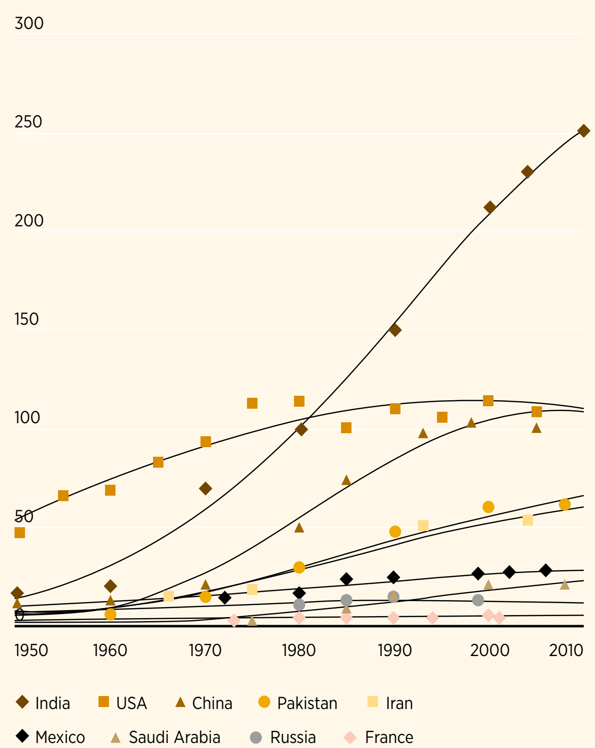
1 Estimated on the basis of IGRAC (2010), AQUASTAT (2011), EUROSTAT (2011), Margat (2008) and Siebert et al. (2010).
2 Average of the 1995 and 2025 'business as usual scenario' estimates presented by Alcamo et al. (2003).

of land surface. The global volume of stored groundwater is poorly known; estimates range from 15.3 to 60 million km^3, including 8 to 10 million km^3 of freshwater, while the remainder – brackish and saline groundwater – is predominant at great depth (Margat, 2008).

Recent model studies have produced global patterns of mean annual groundwater recharge (Döll and Fiedler, 2008; Wada et al., 2010), showing a strong correlation with global mean annual rainfall maps. The mean global groundwater recharge estimated by these models – 12.7·10^3 km^3 per year (Döll and Fiedler, 2008) and 15.2·10^3 km^3 per year (Wada et al., 2010), respectively – is at least three orders of magnitude smaller than the estimated total groundwater storage. What these estimates do not take into account is the possible impact of climate change. However, a recent study by Döll (2009) simulates climate change impacts on the basis of four Intergovernmental Panel on Climate Change (IPCC) scenarios, comparing the model outcomes with those of the reference period 1961–1990. The study concludes that groundwater recharge is likely to increase in the northern latitudes by the 2050s, but strongly decrease (by 30 to 70% or more) in certain currently semi-arid zones, including the Mediterranean, North-Eastern Brazil and South-Western Africa. The numerous narrow and shallow alluvial aquifers (strip aquifers) in dry climatic zones are among the world's most vulnerable with respect to climate change (van der Gun, 2009).

FIGURE 3.8

Groundwater abstraction trends in selected countries (in km^3 per year)



Source: Adapted from Margat (2008, fig. 4.6, p. 107).

Groundwater abstraction causes depletion of groundwater storage until a new dynamic equilibrium is established, under conditions of reduced natural outflow and/or induced recharge. In the world's arid and semi-arid zones, numerous groundwater systems are not resilient enough to accommodatestorage depletion under intensive groundwater development.[9] Evidently, this is true for non-renewable groundwater (Foster and Loucks, 2006), but it applies as well to many aquifers currently being recharged. The result is a progressive depletion of groundwater, accompanied by steadily declining groundwater levels. Konikow and Kendy (2005) estimate that about 700 to 800 km^3 of groundwater has been depleted from aquifers in the USA during the twentieth century. Recently, the Gravity Recovery and Climate Experiment (GRACE) produced estimates of the current rate of groundwater depletion in a number of very large aquifers (Rodell et al., 2009; Famiglietti et al., 2009) and a global simulation model produced estimates for the entire planet (Wada et al., 2010). Results so far show that significant groundwater storage depletion is taking place in many areas of intensive groundwater withdrawal.[10] Physical exhaustion of groundwater storage is a threat in very shallow aquifers only. More commonly, the more important impacts of groundwater depletion are side-effects of the associated declining water levels, and include increasing cost of groundwater (due to larger pumping lifts), induced salinity and other water quality changes, land subsidence, degraded springs and reduced baseflows.

While the bulk of global groundwater resources at shallow and intermediate depths have adequate quality for most uses, gradual changes in local groundwater quality have been observed in zones scattered around the world. The most ubiquitous changes are caused by pollutants produced by humans such as liquid and solid waste, chemicals used in agriculture, manure from livestock, irrigation return flows, mining residues and polluted air. A second category results from the migration of poor quality water into aquifer zones, such as saltwater intrusion in coastal areas or upward migration of deep saline groundwater as a result of groundwater abstraction. Climate change and associated sea level rise are expected to constitute another threat to groundwater quality in coastal areas.

Impacts on other components of the physical environment

The most visible impact of groundwater abstraction and associated changes in the groundwater regime relates to the reduction of natural groundwater outflows. The decrease or disappearance of the baseflow of streams, spring discharge and groundwater-related ecosystems has significantly changed the physical environment in many parts of the world, especially in arid and semi-arid zones.

Figure 3.9 shows a striking example of baseflow reduction due to groundwater storage depletion. In flat areas, the hydraulic setting may be such that part of the direct flow of streams (i.e. the more rapid and often more voluminous flow component) may be lost to adjacent aquifers.

Groundwater abstraction has caused land subsidence in numerous areas around the world where water-saturated compressible formations at relatively shallow depths are in hydraulic connection with intensively exploited aquifers. In flat areas with shallow water tables, land subsidence may generate the need for more intensive drainage, which in turn accelerates land subsidence (Oude Essink et al., 2010).

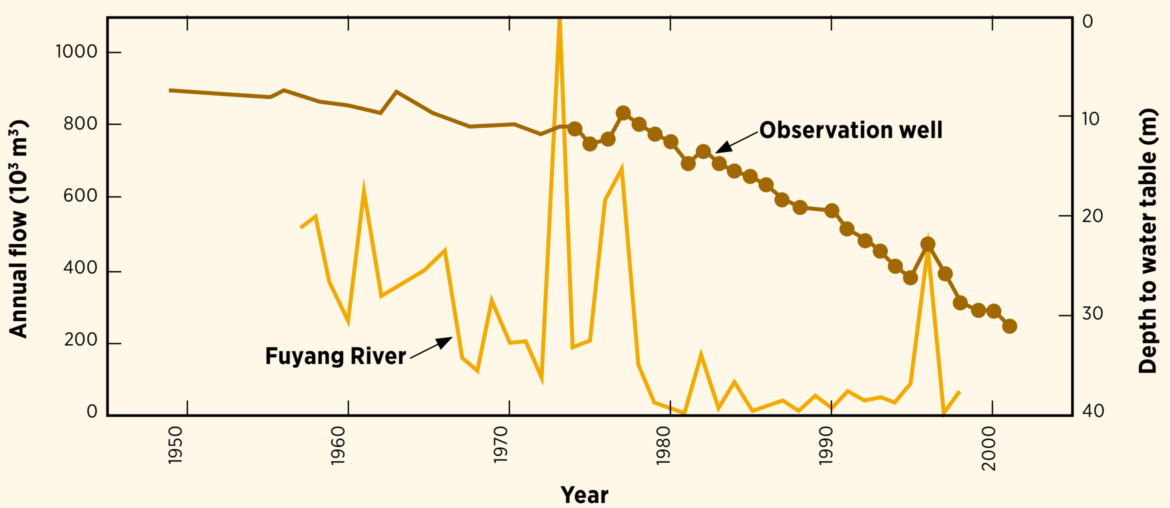
Of particular note is the impact of groundwater depletion on sea level rise. Konikow (2009), Konikow and Kendy (2005) and Wada et al. (2010) argue that the ultimate sink for most of the groundwater removed from aquifers by depletion is the oceans. Although their estimates are not yet precise, they make a plausible argument for groundwater depletion contributing significantly to sea level rise, implying that the current rise in sea level is due in part to influences other than climate change.[11]

Groundwater: Cause for concern or opportunity?

Groundwater constitutes a significant part of the water resource with profound impact on human welfare. Groundwater systems around the world are coming under increasing stress from various anthropogenic and natural factors. In many areas, this threatens the future availability of good-quality groundwater at affordable cost or in situ environmental functions of groundwater. Sound water resources management based on scientific knowledge and paying due attention to groundwater is therefore crucial. It should strive for a balance between present and future benefits

FIGURE 3.9

Stream and well hydrographs from the North China Plain, showing evidence of reduced stream flow caused by groundwater depletion



Source: Konikow and Kendy (2005, fig. 1, p. 318, with kind permission of Springer Science+Business Media).

from groundwater, pay attention to deterioration of groundwater quality, control environmental impacts of groundwater abstraction, and mitigate such impacts in cases where reduced groundwater availability cannot be prevented.

In spite of real concerns about unsustainable abstraction rates and pollution in many parts of the world, groundwater presents many opportunities and will continue to do so in the future if carefully managed. Groundwater's omnipresence and unique buffer capacity have enabled people to settle and survive in dry areas where rainfall and runoff are scarce or unpredictable. Groundwater is a reliable source of domestic water to many rural and urban areas around the world, and subsequent to the silent revolution has contributed and still contributes to significant socio-economic development and poverty alleviation. Groundwater is also likely to play a crucial role in the context of climate change and adaptation. In many water-scarce regions, climate change is expected to result in reduced and more erratic surface water and 'green water' availability. Groundwater recharge will decrease there as well, but the groundwater storage buffer will in most cases ensure uninterrupted water availability, thus triggering a shift in withdrawals from surface water to groundwater. This will reduce overall water supply risks and suggests that groundwater in such regions will provide the key to coping with water scarcity problems imposed or aggravated by climate change during the twenty-first century.

3.2.2 Glaciers

The role of glaciers within mountain hydrology

Mountains are the 'water towers' of the world, receiving much more precipitation than the surrounding lowlands. Their contribution to water supply is of particular significance where the lowlands are arid (Viviroli et al., 2003).

Mountain stream flow is composed of three major elements: rainfall, snow melt and water from glacier melt. The relative importance of these elements, varying through time and with elevation, is largely controlled by temperature and seasonality of precipitation. In many mid-latitude situations there is, on average, no marked seasonality in precipitation; winters are characterized by snowfall and summers by rainfall. In spring, snow melt may dominate the hydrograph, while glacier melt becomes more important in late summer. During years of low snowfall, glacier ice will

"The global groundwater abstraction rate has at least tripled over the past 50 years and continues to increase at an annual rate of 1 to 2%."

begin to contribute melt-water to the streams earlier in the season and will be more dominant in late summer; thus, glaciers act as buffers with waters being released from permanent storage in years of low snowfall and as retaining waters (in the form of ice) in years of heavy snowfall.

The differences between winter and summer become more pronounced moving pole-wards from mid-latitudes, and are reduced moving towards the equator. Precipitation also varies with the type of climate: in Mediterranean climates winter precipitation predominates, while in monsoon climates summer precipitation is more pronounced.

Rising global temperatures have a particular effect on the relative importance of rainfall and snowfall, and on the rates at which glaciers are melting. In general, mountain glaciers are shrinking worldwide – with some notable exceptions, for example, in the Karakoram (Hewitt, 2005). In the short term, the shrinking of glaciers is adding water to stream flow over and above annual precipitation, thus increasing water supply. In the long term (decades to centuries), those additional sources of water will diminish as glaciers disappear, and the buffering effects of glaciers on stream flow regimes will lessen. Overall changes in glacier mass balance are well summarized by Dyurgerov (2010) and the Global Land Ice Measurements from Space (GLIMS) database.

Glacier-related floods are also important in many mountain regions, as illustrated in the examples below.

Regions of the world affected by glacier melt-waters

The global distribution of glaciers and ice sheets is illustrated in Figure 3.10. Most large ice masses are found in regions with sparse human habitation. However, glaciers of the Alps, the Andes, Central Asia, the Caucasus, Norway, New Zealand and Western Canada are important for water supply. In most of these regions glaciers are shrinking with impacts on stream flow as described above.

Populations are growing in all of these regions, and the subsequent demands for water are increasing. In several regions alternative sources of water are being depleted, in particular, groundwater. In most regions, supply is being outstripped by demand. It is arguable that changes in demand are often more significant than changes in supply; thus, care must be taken to consider both sides of the supply/demand equation in assessing water resources.

Examples from the Himalayan region

The basins of the Brahmaputra, Ganges and Indus, encompassing the Himalaya and Karakoram (illustrated in Figure 3.11) demonstrate the importance of glaciers on stream flow. Within these basins live some 0.8 billion people dependent on stream flow for water supply and at risk from glacier-related floods.

This region is characterized by great climatic, glaciological and hydrological diversity. The eastern Himalaya is dominated by the summer monsoon. Westward, the intensity of the monsoon diminishes, while in the Karakoram, intensive summer precipitation occurs only in exceptional years. Local precipitation varies greatly from less than 5,000 mm per year on the southern flanks of the eastern Himalaya to less than 250 mm per year on the northern slopes (Young, 2009).

Figure 3.12 illustrates glacier extent in the region. Most of the glaciers in the Himalaya are relatively small; they are found predominantly at high elevations and respond relatively quickly to global warming. Large glaciers dominate the Karakoram with areal extents of greater than 500 km^2. Such glaciers, many of which are surge-type, extend to elevations below 3,000 m and respond very slowly to changes in climate. Many are currently growing in areal extent and probably also in mass.

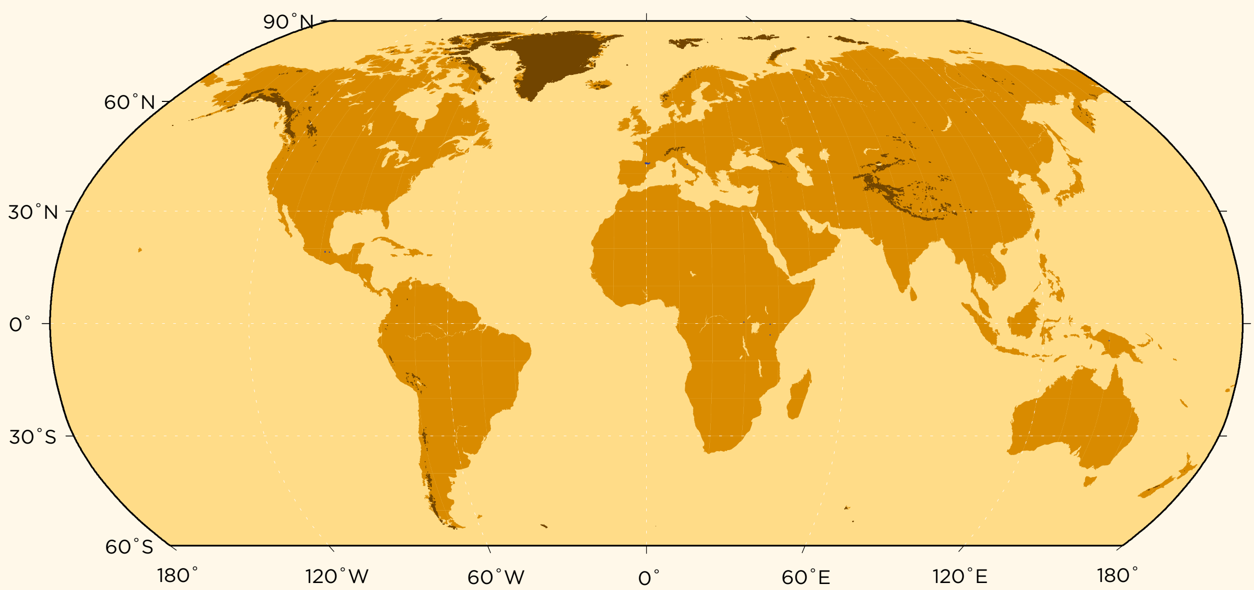
Glacier melt contribution to stream flow

The significance of glacier melt contribution to stream flow may be divided into two components:

- *The melting of glacier ice in the ablation zone,* that is, the part of the glacier with an annual net loss of mass. Such melting varies in importance within the Himalayan region. In the eastern Himalaya glacier,

FIGURE 3.10

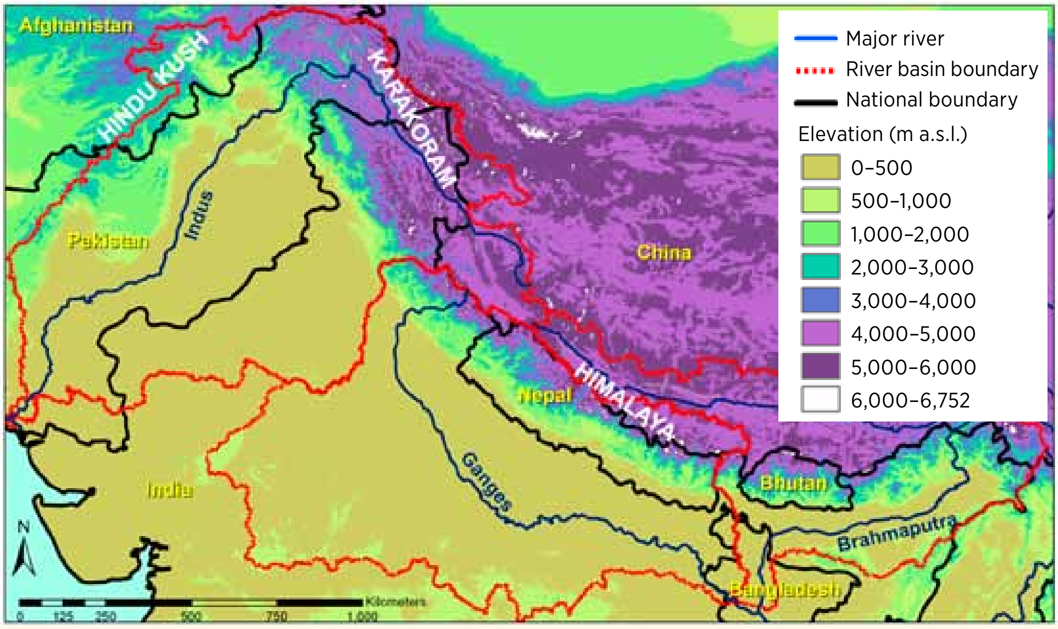
Global distribution of glaciers and ice sheets (Antarctica excluded)



Source: Armstrong et al. (2005, courtesy B. H. Kaup, National Snow and Ice Data Center, GLIMS).

FIGURE 3.11

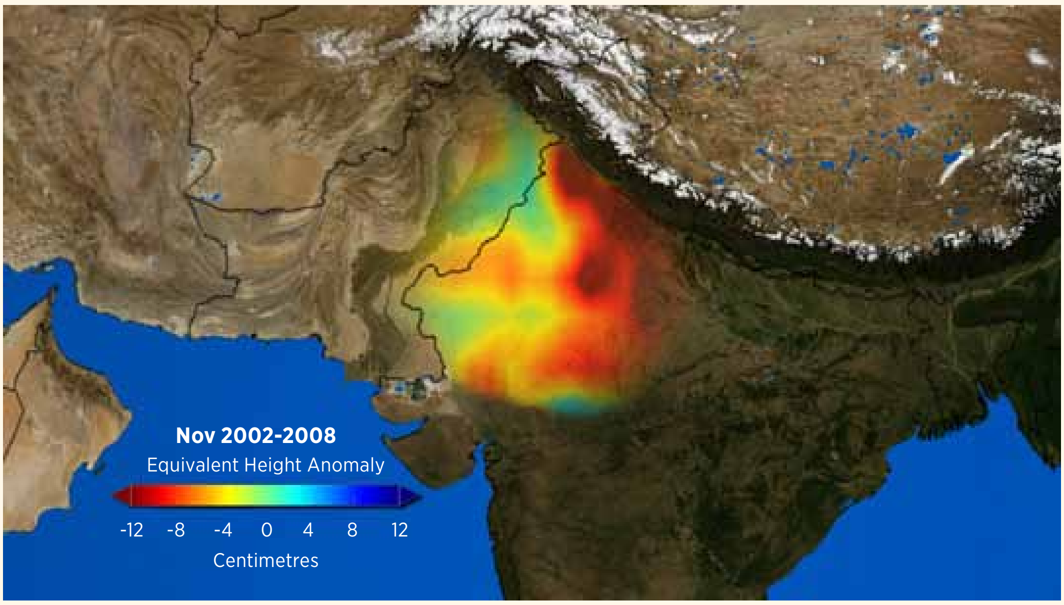
Delineation of the basins of the Brahmaputra, Ganges and Indus



Source: Miller et al. (2011 [in press], fig. 1, p.7, using US Geological Survey ESRI data).

FIGURE 3.12

GRACE satellite image showing the extent of glacier cover in the Himalaya – Karakoram and estimation of groundwater depletion in north-west India



Note: The loss of 109 km³ over a six-year period is significant.
Source: NASA GRACE Satellite image (http://www.nasa.gov/topics/earth/features/india_water.html), T. Schindler and M. Rodell.

ice melt is completely overshadowed by monsoon rainfall and snow melt, with the ice melt contributing less than 3% of annual stream flow. In the Karakoram, the glacier melt contribution is much more significant, reaching more than 20% of annual flow in some years during late summer.

- *The contribution derived from shrinkage of the glacier mass due to global warming,* that is, water being released from permanent storage and adding to stream flow derived from annual precipitation. While there is good evidence that most glaciers in the Himalaya are, very slowly, losing mass, many glaciers in the Karakoram are gaining mass (Hewitt, 2005). It has been clearly demonstrated that glaciers in different parts of the region are shrinking (or in some instances gaining) mass at very different rates (Scherler et al., 2011.) Those that are shrinking are doing so very slowly, probably contributing much less than 1% to annual stream flows. It is likely that very large glaciers will contribute melt-water to stream flow at much the same rate for many decades and possibly centuries; however, some glaciers will recede or even disappear (as in Peru [Oblitas de Ruiz, 2010]), with the resulting decrease in water supply for various uses, as in some areas of Argentina, Chile and Peru (ECLAC, 2009).

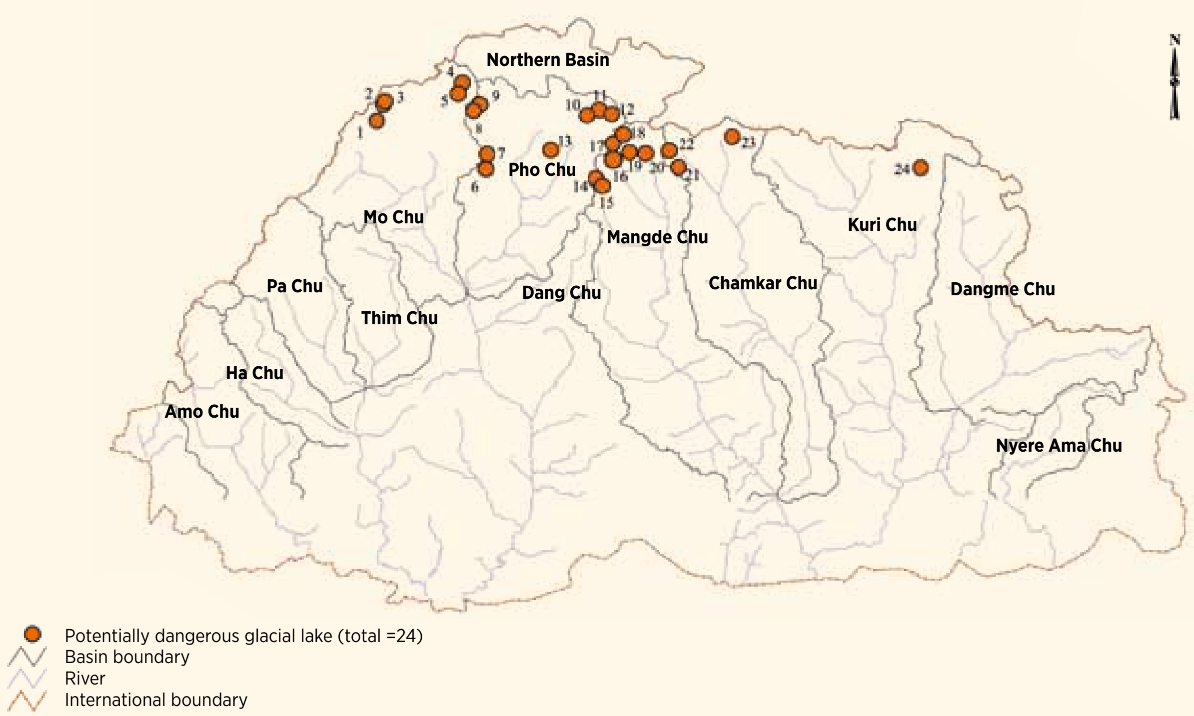
FIGURE 3.14

Lugge Tsho Glacial lake, Bhutan

Source: Mool et al. (2001b, plate 9.13, p. 93).

FIGURE 3.13

Dangerous glacier dammed lakes within Bhutan



Source: Mool et al. (2001a, p. 109).

Glacier-related floods

There are two types of glacier-related floods in the region: glacier lake outburst floods (GLOFs) and outbursts of glacier-dammed lakes (jökulhlaups).

GLOFs result from small pro-glacial lakes – that is lakes impounded by terminal and lateral moraines in front of the glacier termini – emptying very rapidly, producing floods of high intensity and short duration. With glaciers retreating due to global warming, such lakes are becoming larger. Sudden releases can result from the collapse of the retaining moraine or as a result of landslides into the lake with sudden displacement of the waters. The risks from such floods are increasing. There are many thousand such glacier lakes in the region. GLOFs can cause extensive damage downstream, with loss of life and economic damage from destruction of bridges, hydro plants and other infrastructure (Ives et al., 2010). In Bhutan, there are over 2,400 such lakes, 24 of which have been identified as potentially catastrophic (Figures 3.13 and 3.14).

Jökulhlaups result from the sudden release of water from lakes impounded by glaciers that have dammed valleys. Sudden release of lake waters can be truly catastrophic for the Karakoram (Hewitt, 1982), as illustrated in Figure 3.15. In the 1920s, successive floods initiated on the Shyok River resulted in an 18 m increase in the water level at Attock 1,400 km downstream, with catastrophic results in the plains of the Punjab.

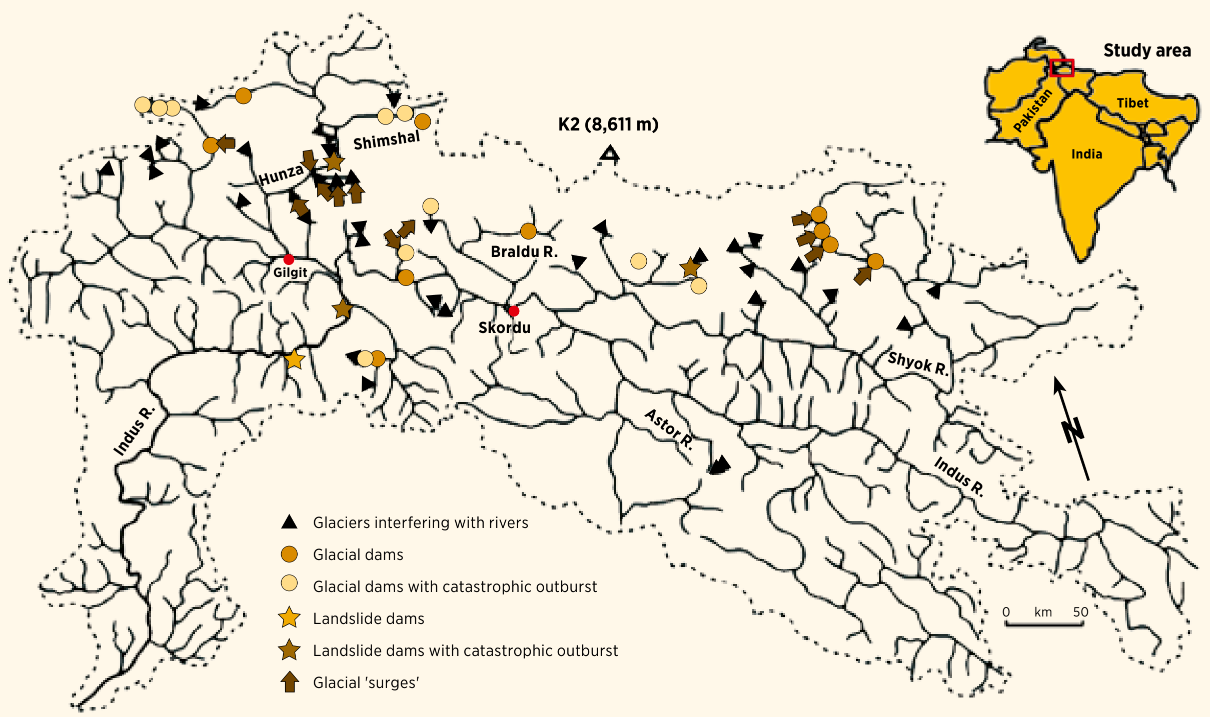
Policy options to deal with uncertainty and risk related to glaciers in the Himalayan region

The transboundary nature of all three of the river systems concerned – with headwaters in China, mid-sections in Nepal/Bhutan and/or India, and lower sections in Pakistan or Bangladesh – means that policy options for water resources management need to be considered within a broad political and economic context. The sharing of water resources between these countries is a challenge.

Demands for water supply are growing with dramatic population increases, a situation further complicated by the migration of people from rural to urban settings. In addition, economic development and higher standards of living are increasing demands for water. All of these issues pose challenges for water managers.

FIGURE 3.15

Indus River: Glacier dams and related events



Source: Hewitt (1982, p. 260, by permission IAHS).

“Wastewater management solutions also need to be combined with public education efforts, such as those related to personal hygiene and environmental education.”

Alternative water supplies, particularly groundwater resources in north-west India vital to human life and livelihoods, are being depleted unsustainably (Figure 3.12). This has important implications for overall water supply.

A summary of how the countries in the region are adapting to the effects of climate change is provided in ICIMOD (2009). However, there is a general perception within most government circles that glacier melt and shrinkage will be highly detrimental to water supply. This perception is almost certainly misplaced. Most glaciers will continue to shrink very slowly, adding water to the streams over and above annual precipitation, but only in very small quantities relative to precipitation.

An example of how Bhutan is addressing flood risk issues is given within the UNDP Adaptation Learning Mechanism. The objective of the project is to reduce climate change-induced GLOF risks. Through the project, the Government of Bhutan will integrate long-term climate change-induced risks into the existing disaster risk management framework. It will demonstrate practical measures to reduce GLOF risks, such as installing pumps to reduce lake levels and introducing early warning systems to alert downstream populations.

3.3 Water quality

The ‘quality’ of water is a relative term. The notion of ‘good’ or ‘bad’ water quality is not only a function of its state and what it contains, but also depends on what it is used for. ‘Pure’ water does not exist in nature but only in the laboratory, and all substances may be pollutants depending on their concentration in water. This is one of the reasons health professionals often prefer to use the term ‘safe’ water rather than ‘clean’ water.

Sufficient water supply of appropriate quality is a key ingredient in the health and well-being of humans and ecosystems, and for social and economic development. Water quality is becoming a global concern of increasing significance, as risks of degradation translate directly into social economic impacts. Although there have been some regional successes in improving water quality, there are no data to suggest that there has been an overall improvement in water quality on a global scale.

Water quality is inextricably linked with water quantity as both are key determinants of supply. Compared to water quality, water quantity has received far more investment, scientific support and public attention in recent decades. However, water quality is just as important as water quantity for satisfying basic human and environmental needs. Moreover, the two are inextricably linked, with poor water quality impacting water quantity in a number of ways. For example, polluted water that cannot be used for drinking, bathing, industry or agriculture may effectively reduce the amount of water available for use in a given area (UNEP, 2010). The more polluted the water is, the greater the incremental cost of treatment required to return it to a useable standard (UNEP, 2010).

According to Stellar (2010), ‘The link between quality and quantity can take different forms in the cases of ground water and surface water. Where subterranean aquifers are concerned, there is an explicit connection between over-use and quality degradation’. Excessive pumping of groundwater over time can diminish water quality in two ways. First, quality can be affected through increased concentrations of naturally occurring compounds that become dangerously high as the amount of water dwindles, as in the case of India where fluorosis potentially threatens or directly affects millions of people. Second, quality can be affected by increasing salinity levels as a result of saltwater intrusion into coastal aquifers, as in the case of Cyprus and the Gaza Strip (Stellar, 2010). The most immediate problem that saltwater intrusion typically causes is a reduction in the amount of water available for human consumption, but it also directly impacts other uses including those relating to agriculture and industry.

Overuse of surface water, such as rivers and lakes, can lead to increased concentrations of harmful substances present in the water due to pollution or mineral leaching. 'A marked example of this is seen in the case of the Rio Grande River, where decreased flows in summer months coincide with large declines in water quality. During the dry season, pathogen concentrations increase by almost 100 times' (Stellar, 2010).

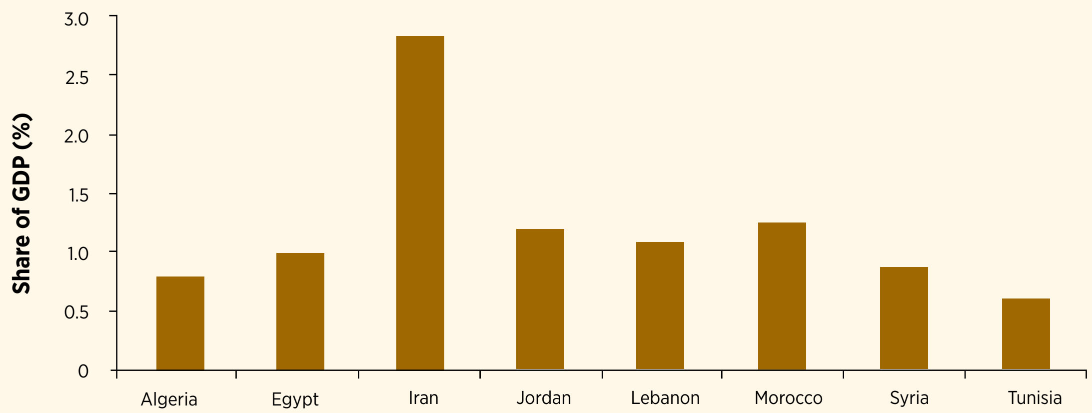
Policy-makers must make a concerted effort to better integrate the issues of water quantity and water quality in their responses. In turn, they need the support of the research community who can help to better quantify the problems, as well as the development of remedial solutions. Without an appropriate level of intervention, the major social, economic and environment-related risks, uncertainties and impacts related to water quality are expected to increase.

Socio-economic development is dependent on water quality. Risks to human and ecosystem health are linked to poor water quality, which in turn threatens socio-economic development. Ecosystem health has historically been a concern of the richer, more developed countries and their environmental movements. However, increasing recognition of the multitude of benefits of ecosystem goods and services, including wastewater treatment, has gradually made ecosystem health an important socio-economic issue, even in the poorest countries. Water polluted with toxic substances, such as inorganic compounds and untreated sewage, degrades the function of aquatic ecosystems by reducing the multifaceted goods and services they are able to provide. As many of the world's poorest people depend directly upon these goods and services for their existence, this situation further complicates efforts to alleviate poverty (MA, 2005*a*,*b*).

In terms of responses, there is a need for cost-effective options for collection, treatment and disposal of human wastes. It is estimated that over 80% of used water worldwide is not collected or treated (Corcoran et al., 2010). Wastewater management solutions also need to be combined with public education efforts, such as those related to personal hygiene and environmental education. Studies have shown that the provision of improved sanitation and safe drinking water could reduce diarrhoeal diseases by nearly 90% (WHO, 2008*b*). There is also a need to direct efforts toward industries using or producing toxic substances. Development of clean technology and substitution processes, combined with cost-efficient treatment options, is a priority component. The control of non-point sources of pollution, particularly nutrients leading to eutrophication, is an increasing global challenge. Regulations and efficient regulatory enforcement are essential – alongside institutional efforts to strengthen emergency responses, in particular when the safety of drinking water supplies is compromised during natural disasters. This issue

FIGURE 3.16

Annual cost of the environmental degradation of water



Source: World Bank (2007, fig. 4.4, p. 109, from data sources cited therein).

will increase in importance with the emerging threats brought about by climate change impacts.

Water quality is linked to human health. Human health risks are without doubt the major and most widespread concern linked to water quality. Approximately 3.5 million deaths related to inadequate water supply, sanitation and hygiene occur each year, predominantly in developing countries (WHO, 2008*a*) (see Section 4.1 and Chapter 34). Diarrhoeal diseases, often related to contaminated drinking water, are estimated to cause the death of more than 1.5 million children under the age of five per year (Black et al., 2010). The MDGs state that waterborne diseases related to unsafe drinking water supplies represent one of the major threats to the world's vulnerable poor.

Toxic water contamination is less widespread, but remains an important issue in many regions, particularly emerging economies. The release of toxic wastes from waste dumps and industrial enterprises is also a major threat and expense to the provision of safe water in the developing world. An important share of the total burden of disease worldwide – around 10% – could be prevented by improvements related to drinking water, sanitation, hygiene, and use of environmental management and health impact assessments (see Section 4.1).

TABLE 3.3

Key water quality risks

Risk	Waterborne diseases	Toxic contamination	Oxygen deficit and eutrophication	Poisoning	Ecosystem modification
Severity					
	Millions of cases Increasing trends	Thousands of cases of serious impacts in hot spots Lack of reliable documentation	Thousands of km^2 Decline in coastal fisheries Decrease in recreational value	Hundreds of km^2 Destruction of fisheries	Increase in invasive species Increase in invasive pests Increase in turbidity
Main drivers					
Natural Processes	Increasing flooding incidents	Saltwater intrusion	Heat waves		Seawater intrusion Heating Erosion after forest fires
Social	Urban migration Poverty	Waste disposal attitudes Poverty	Poor application of fertilizers	Waste disposal attitudes Poverty	Poverty
Economic	Inadequate investment in wastewater treatment	Industrial waste and spills	Intensive agriculture Mining Urban wastewater Industrial wastewater	Agriculture Urban wastewater Industrial wastewater Mining	Agriculture Forestry Urban wastewater Industrial wastewater Hydropower
Response options					
Interventions	Urban wastewater treatment	Industrial waste treatment Clean technology Warning systems	Sustainable agricultural practices Nutrient removal in wastewater	Industrial waste treatment Clean technology Integrated pest management	Sustainable agricultural practices Sustainable forestry Nutrient removal in wastewater

Poor quality water is expensive. Poor water quality incurs many economic costs: degradation of ecosystem services; health-related costs; impacts on economic activities such as agriculture, industrial production and tourism; increased water treatment costs; and reduced property values among others. In some regions these costs can be significant (UNEP, 2010). Figure 3.16 shows the estimated annual cost of poor water quality in countries in the Middle East and North Africa as a share of GDP (World Bank, 2007). Projections for these and other regions show increasing scarcity of freshwater in forthcoming years. The costs associated with addressing water quality problems can therefore be expected to increase.

Conversely, taking action to improve or ensure the maintenance of water quality can save lives and achieve significant savings. Examples include a reduction in industrial production costs and the use of natural waste treatment services provided by freshwater ecosystems. Although more research is needed to better understand and quantify the economic costs and benefits of industry and ecosystem services, most evidence suggests that many social and economic benefits derived from addressing water quality issues today will increasingly outweigh the future costs of inaction or delayed responses.

A global water quality assessment framework is necessary. While there are many possible ways to address

TABLE 3.4

Summary of possible water quality interventions by scale

Scale	Education and capacity-building	Policy/law/ governance	Financial/ economic	Technology/ infrastructure	Data/ monitoring
International/national	Initiate training and awareness building	Institute integrated approaches Institute pollution prevention	Institute polluter/ beneficiary pays system	Promote best practice and support capacity building	Develop monitoring framework
Watershed	Strategic level for raising awareness of the impacts of individuals on water quality Establish training for practitioners and develop best practice	Create watershed-based planning units. Develop water quality goals	Institute pricing systems Institute cost recovery Create incentives for efficiency	Invest in infrastructure and appropriate technologies	Build regional capacity to collect and process water quality data
Community/ household	Connect individual/ community behaviour to water quality impacts. Build capacity to make improvements in sanitation/ wastewater treatment	Amend codes to allow innovative storm water treatment options. Promote access to information	Encourage investments	Consider decentralized treatment technologies	Carry out and analyse household/ community surveys

Source: Adapted from UNEP (2010, p. 73).

water quality issues from the international to the household level, there is an urgent lack of water quality data to support decision-making and management processes. A global water quality assessment framework is needed to draw on existing national, regional and key basin-level data sources. Such a framework would go well beyond the current Global Environment Monitoring System (GEMS)[12] mandate to include a host of other international, regional and national programmes. According to Alcamo (2011) this type of framework could value freshwater goods and services, provide an assessment of water quality and data push, support the development and application of international water quality guidelines, develop international governance and institutions to support water quality protection, and include an assessment of ecologically based technologies for restoring water quality.

Such a framework would also help to increase understanding of the state of water quality, its causes and recent trends; identify hot spots; test and validate policy and management options; provide a foundation for scenarios used to understand and plan for appropriate future actions; and provide much-needed monitoring bench markers (Alcamo, 2011). As described in Chapter 6, there is growing interest from multiple stakeholders in improved data, information and accounting, all of which needs to be translated into improved data availability. Technological advancements are also making it easier to monitor and report on various dimensions of water resources. The main constraints to fulfilling these important needs are institutional structures and mandates, as well as political will, even though the benefits of improved water quality monitoring are likely to outweigh the costs, especially in areas with dense human populations or intense agricultural activity.

3.3.1 Water quality risks and potential interventions

The multitude of water quality parameters, uncertainties and impacts makes water resources management a complex and multidimensional issue, particularly with respect to human activities. Improved management of vulnerability and risks is essential to cope with as-yet unknown and unexpected factors in an era of accelerated changes and new uncertainties. Table 3.3 provides a summary of water quality risks describing the severity of each, the main drivers involved and the potential response options.

In addition to the response options provided in Table 3.3, some broad response options are provided in Table 3.4.

Notes

1 This measure is not necessarily a robust indicator of a country's potential for water-related challenges. Canada and Brazil, for example, both have a very high level of available water per capita, yet are still subject to various water-related problems.

2 Teleconnections are climate anomalies that are related but often widely spaced in distance and/or time. The relationship between two climate patterns is not necessarily one of cause and effect. Often unusual climate phenomena are caused by some third factor, such as when El Niño events increase the chance of above average precipitation in the south-west USA from January through March and increase the chance of drought in Indonesia from June through August. For more information see http://earthobservatory.nasa.gov/Features/HighWater/high_water1a.php

3 For more information see http://www.pmel.noaa.gov/tao/elnino/nino-home.html

4 For more information see: http://jisao.washington.edu/pdo/

5 For a good resource on NAO, its climate impacts and other information, readers are referred to http://www.ldeo.columbia.edu/res/pi/NAO/

6 See the website of the Atlantic Meridional Overturning Circulation Program for more details: http://www.atlanticmoc.org/

7 Almost all values mentioned in this paragraph are globally aggregated or averaged, and thus cannot be used to draw conclusions on conditions at a local or regional scale.

8 Siebert et al. (2010) estimate global consumptive irrigation water use at 1,277 km^3 per year, or 48% of global agricultural water withdrawals. Their estimate for groundwater use is 545 km^3 per year, which is fairly consistent with the estimated global groundwater abstraction for irrigation, taking into account irrigation water losses.

9 Examples of large aquifers in this category are the Highland Plains and Central Valley aquifers in the USA, the north-west India plains aquifers, the North China Plain aquifer and the Australian Great Artesian Basin.

10 For more details see Chapter 36.

11 For more details see Chapter 36.

12 The United Nations GEMS/Water Programme provides scientifically sound data and information on the state and trends of global inland water quality required as a basis for the sustainable management of the world's freshwater to support global environmental assessments and decision-making processes (see http://www.gemswater.org/).

References

AIRMAP (J. A. Bradbury and C. P. Wake). *El Nino, The North Atlantic Oscillation and New England Climate. Winter Season Teleconnections and Climate Prediction.* Durham, NH, Climate Change Research Center, Earth Sciences, University of New Hampshire. http://airmap.unh.edu/background/nao.html

Alcamo, J. 2011. *The Global Water Quality Challenge.* A presentation at the UNEP Water Strategy Meeting, Nairobi, 7 June 2011.

Alcamo, J., P. Döll, P., Henrichs, Th., Kaspar, F., Lehner, B., Rösch, Th. and Siebert, S. 2003. Global estimates of water withdrawals and availability under current and future 'business-as-usual' conditions. *Hydrological Sciences Journal,* Vol. 48, No. 3, pp. 339–48.

AQUASTAT. 2011. Online database. Rome, Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/nr/water/aquastat/data/query/index.html (Accessed August 2011).

Armstrong, R., Raup, B., Khalsa, S. J. S., Barry, R., Kargel, J., Helm, C. and Kieffer, H. 2005. *GLIMS Glacier Database.* Boulder, Colo., National Snow and Ice Data Center. http://nsidc.org/glims/ and http://nsidc.org/glims/glaciermelt/index.html.

Black, R. E., Cousens, S., Johnson, H. L., Lawn, J. E., Rudan, I., Bassani, D. G., Jha. P., Campbell, H., Walker, C. F., Cibulskis, R., Eisele, T., Liu, L. and Mathers, C. 2010. Presentation for the Child Health Epidemiology Reference Group of WHO and UNICEF. Global, regional, and national causes of child mortality in 2008: a systematic analysis. *The Lancet,* Vol. 375, No. 9730, pp. 1969–87. http://www.who.int/child_adolescent_health/data/cherg/en/index.html (Accessed 3 October 2011.)

Comprehensive Assessment of Water Management in Agriculture. 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture.* London/Colombo, Earthscan/International Water Management Institute.

Corcoran, E., Nellemann, C., Baker, E., Bos, R., Osborn, D. and Savelli, H. (eds). 2010. *Sick Water? The Central Role of Wastewater Management in Sustainable Development. A Rapid Response Assessment.* The Hague, UN-Habitat/UNEP/GRID-Arendal.

Döll, P. 2009. Vulnerability to the impact of climate change on renewable groundwater resources: a global-scale assessment. *Environm. Res. Lett.* Vol. 4, 035006.

Döll, P. and Fiedler, K. 2008. Global-scale modelling of groundwater recharge. *Hydrol. Earth Syst. Sci.,* Vol. 12, pp. 863–885.

Dyurgerov, M. B. 2010. *Reanalysis of Glacier Changes: From the IGY to the IPY, 1960–2008.* Data of Glaciological Studies, Publication 108, Moscow, October (in English).

ECLAC (United Nations Economic Commission for Latin America and the Caribbean) (coordinated by L. M. Galindo and C. de Miguel). 2009. *Economics of Climate Change in Latin America and the Caribbean: Summary.* LC/G.2425. http://www.cepal.org/publicaciones/xml/3/38133/02_Economics_of_Climate_Change_-_Summary_2009.pdf

EUROSTAT. 2011. Online database. Brussels, European Commission (EC). http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/

Famiglietti, J., Swenson, S. and Rodell, M. 2009. *Water Storage Changes in California's Sacramento and San Joaquin River Basins, Including Groundwater Depletion in the Central Valley.* PowerPoint presentation, American Geophysical Union Press Conference, 14 December, 2009, CSR, GFZ, DLR and JPL.

Foster, S. and Loucks, D. 2006. *Non-renewable Groundwater Resources.* UNESCO-IHP Groundwater series No. 10. Paris, UNESCO.

Giordano, M. and Vilholth, K. (ed.) 2007. *The Agricultural Groundwater Revolution.* Wallingford, UK, Centre for Agricultural Bioscience International (CABI).

Hewitt, K., 1982. *Natural Dams and Outburst Floods of the Karakoram Himalaya.* Proceedings of the Symposium on Hydrological Aspects of Alpine and High Mountain Areas. International Association of Hydrological Sciences (IAHS) Publication No. 138. Wallingford, UK, IAHS Press.

Hewitt, K. 2005. The Karakoram Anomaly? Glacier expansion and the 'elevation effect', Karakoram Himalaya. *Mountain Research and Development,* Vol. 25, No. 4, pp. 332–40.

ICIMOD (International Centre for Integrated Mountain Development). 2009. *Water Storage: A Strategy for Climate Change Adaptation in the Himalayas.* Publication no. 56. Kathmandu, ICIMOD. http://books.icimod.org/uploads/tmp/icimod-water_storage.pdf

IGRAC (International Groundwater Resources Assessment Centre). 2010. *Global Groundwater Information System (GGIS).* Delft, The Netherlands, IGRAC. http://www.igrac.net

Ives, J., Shresta, R. and Mool, P. 2010. *Formation of Glacial Lakes in the Hindu Kush-Himalayas and GLOF Risk Assessment.* Kathmandu, International Centre for Integrated Mountain Development (ICIMOD).

JISAO (Joint Institute for the Study of the Atmosphere and Ocean). 2000. *The Pacific Decadal Oscillation.* University of Washington, Seattle, Wash., JISAO. http://jisao.washington.edu/pdo/

Konikow, L. and Kendy, L. 2005. Groundwater depletion: A global problem. *Hydrogeology Journal,* doi:10.1007/s10040-004-0411-8

Konikow, L. 2009. *Groundwater Depletion: A National Assessment and Global Perspective.* The Californian Colloquium on Water, 5 May 2009. http://youtube.com/watch?v=Q5s0Uit8V6s.

Llamas, M. R. and Garrido, A. 2007. Lessons from intensive groundwater use in Spain: economic and social benefits and conflicts. M. Gordano and K. G. Vilholth (ed.) *The Agricultural Groundwater Revolution.* Wallingford, UK, Centre for Agricultural Bioscience International (CABI), pp. 266–95.

Llamas, M. R. and Martínez-Santos, P. 2005. Intensive groundwater use: a silent revolution that cannot be ignored. *Water Science and Technology Series,* Vol. 51, No. 8, pp. 167–74. London, IWA Publishing.

Margat, J. 2008. *Les eaux souterraines dans le monde.* Paris, BGRM/Editions UNESCO.

MA (Millennium Ecosystem Assessment). 2005*a*. *Ecosystems and Human Well-Being: Wetlands And Water Synthesis.* Washington DC, World Resources Institute (WRI).

––––. 2005*b*. *Ecosystems and Human Well-Being: Synthesis.* Washington DC, Island Press.

Miller, J. M., Rees, H. G., Young, G., Warnaars, T., Shrestha, A. B. and Collins, D. C. 2011 (in press). *What is the Evidence for Glacial Shrinkage Across the Himalayas?* Systematic Review No. CEE10-008 (Collaboration for Environmental Evidence [CEE]). Wallingford, UK, Centre for Ecology and Hydrology (CEH).

Mool, P. K., Bajracharya, S. R. and Joshi, S. P. 2001a. *Inventory of Glaciers, Glacial Lakes, and Glacial Lake Outburst Floods: Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region – Nepal.* Kathmandu, International Centre for Integrated Mountain Development (ICIMOD).

Mool, P. K., Bajracharya,S. R., Joshi, S. P., Wangda, D., Kunzang, K. and Gurung, D. R. 2001b. *Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods: Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region – Bhutan.* Kathmandu, International Centre for Integrated Mountain Development (ICIMOD) and United Nations Environment Programme (UNEP). http://www.icimod.org/publications/index.php/search/publication/130.

NOAA/PMEL/TAO (National Oceanic and Atmospheric Administration)/ Pacific Marine Environmental Laboratory/ Tropical Atmosphere Ocean Project). n.d. *El Niño Theme Page.* Seattle, Wash., NOAA/PMEL/TAO. http://www.pmel.noaa.gov/tao/elnino/nino-home.html

Oblitas de Ruiz, L. 2010. *Servicios de agua potable y saneamiento en el Perú: beneficios potenciales y determinantes de éxito.* LC/W.355. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/4/41764/lcw355e.pdf

Oude Essink, G. H. P., van Baaren, E. S. and de Louw, P. G. B. 2010. Effects of climate change on coastal groundwater systems: a modelling study in the Netherlands. *Water Resources Research,* Vol. 46. Washington DC, American Geophysical Union (AGU).

Rodell, M., Velicogna, I. and Famiglietti, J. 2009. Satellite-based estimates of groundwater depletion in India. *Nature,* Vol. 460, pp. 999–1002.

Scherler, D., Bookhagen, B. and Strecker, M. R. 2011. Hillslope-glacier coupling: the interplay of topography and glacial dynamics in High Asia. *J. Geophys. Res.,* Vol. 116, F02019.

Shah, T. 2007. The groundwater economy of South Asia: an assessment of size, significance and socio-ecological impacts. M. Giordano and K. G. Villholth (eds) *The Agricultural Groundwater Revolution: Opportunities and Threats to Development.* Colombo, Sri Lanka/Wallingford, UK, International Water Management Institute (IWMI)/Centre for Agricultural Bioscience International (CABI), pp. 7–36.

––––. 2009. Climate change and water: India's opportunities for mitigation and adaptation. *Environm. Res. Lett.* Vol. 4, 035005.

Siebert, S., Burke, J. Faures, J., Frenken, K., Hoogeveen, J., Döll, P. and Portmann, T. 2010. Groundwater use for irrigation – a global inventory. *Hydrol. Earth Syst. Sci.,* Vol. 14, pp. 1863–80.

Stellar, D. 2010. Can we have our water and drink it, too? Exploring the water quality-quantity nexus. *State of the Planet* blog. New York, Earth Institute, Columbia University. http://blogs.ei.columbia.edu/2010/10/28/can-we-have-our-water-and-drink-it-too-exploring-the-water-quality-quantity-nexus/ (Accessed September 2011.)

UNEP (United Nations Environment Programme). 2010. *Clearing the Waters. A Focus in Water Quality Solutions.* Nairobi, UNEP. http://www.unep.org/PDF/Clearing_the_Waters.pdf

––––. 2011. *Policy Brief on Water Quality.* Nairobi, UNEP. http://www.unwater.org/downloads/waterquality_policybrief.pdf

Van der Gun, Jac A. M. 2009. Climate change and alluvial aquifers in arid regions: examples from Yemen. *Climate Change and Adaptation in the Water Sector.* London, Earthscan, pp. 143–58.

Viviroli, D., Weingartner, R. and Messerli. B. 2003. Assessing the hydrological significance of the world's mountains. *Mountain Research and Development,* Vol. 23, No. 1, pp. 32–40.

Wada, Y., Van Beek, L. P. H., Van Kempen, C. M., Reckman, J. W. T. M., Vasak, S. and Bierkens, M. F. P. 2010. Global depletion of groundwater resources. *Geophysical Research Letters,* Vol. 37, L20402. doi:10.1029/2010GL044571

WHO (World Health Organization). 2008*a*. *The Global Burden of Disease: 2004 Update.* Geneva, WHO.

––––. 2008*b*. *Safer Water, Better Health: Costs, Benefits and Sustainability of Interventions to Protect and Promote Health.* Geneva, WHO.

WHYMAP, 2008. *Groundwater Resources of the World,* Map 1: 25 M. Paris, UNESCO/IAH/BGR, CGMW, IAEA.

World Bank. 2007. *Making the Most of Scarcity: Accountability for Better Water Management Results in the Middle East and North Africa.* Washington DC, The World Bank. http://siteresources.worldbank.org/INTMENA/Resources/04-Chap04-Scarcity.pdf

WWAP (World Water Assessment Programme). 2009. *Water in a Changing World. World Water Development Report 3.* Paris/London, UNESCO Publishing/Earthscan.

Young, G. J. 2009. *The Elements of High Mountain Hydrology with Special Emphasis on Central Asia.* Proceedings of Workshop, Almaty, Kazakhstan, 28–30 November 2006. Joint Publication of UNESCO-IHP and the German National Committee for IHP/HWRP, 9–18. http://www.indiaenvironmentportal.org.in/files/Glacier%20in%20Asia_lowres.pdf

CHAPTER 4

Beyond demand: Water's social and environmental benefits

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Red-eyed tree frog

The many benefits humans derive through water are by no means limited to the five major use sectors described in Chapter 2. Water also provides a range of benefits through its impacts on human health. Healthy ecosystems provide an even broader array of benefits and services to individuals and societies. In addition to these benefits, water can also create serious risks when there is too much of it, as in the case of floods, or too little of it, as during periods of drought, especially in areas already subject to the processes of desertification and land degradation. Unfortunately, in many parts of the world, access to water's benefits are not equitably balanced, nor are vulnerabilities to water-related hazards, which disproportionally affect the poorest populations, and women and children in particular. This chapter examines water in relation to each of these important issues.

The first section, on water and human health, focuses on water-related diseases in the context of public health interventions, water management, drinking water supply and sanitation, and hygiene, identifying trends and hotspots, key external drivers and related uncertainties, and provides insights on actions for combating the major water-related disease burdens at different levels. The following section describes how gender differences in access to and control over water resources are key ingredients of many water-related challenges worldwide. The third section explores how healthy ecosystems offer solutions to achieving water-related objectives and help reduce uncertainty and risk as they deliver multiple benefits (or services) that are essential for sustainable development – many of these vital services are derived directly from water, and all are underpinned by it. The fourth section, on water-related hazards, reports on recent trends and examines the increased risks disasters create with respect to property, lives and livelihoods. The fifth section describes how the processes of desertification, land degradation and drought (DLDD) are increasing pressure on water resources, adding a new layer of uncertainty and risk in regions already facing water scarcity, and presents different measures that are being applied worldwide to reduce the impacts of DLDD.

The chapter closes with a discussion of the current balance between limited and often variable water supplies (Chapter 3), growing demands from the major user groups (Chapter 2), and the need to maintain benefits and reduce risks (this chapter). This section addresses concepts such as water stress and water scarcity, making the case that balancing the benefits and maximizing the returns from water and its multiple uses is essential for sustainable development and poverty eradication.

With the exception of Section 4.6, the material in this chapter has been condensed from the challenge area reports (Part 3/Volume 2) 'Water and health' (Chapter 34), 'Ecosystems' (Chapter 21), 'Water-related disasters' (Chapter 27) and 'Desertification, land degradation and drought and their impacts on water resources in the drylands' (Chapter 28) as well as the special report 'Water and gender' (Chapter 35).

4.1 Water and human health

Improving water resource management, increasing access to safe drinking water and basic sanitation, and promoting hygiene (WaSH) have the potential to improve the quality of life of billions of individuals. The global importance of water, sanitation and hygiene for improving health is reflected in the United Nations Millennium Development Goals (MDGs), explicitly, Goal 7, Target c, which aims to reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015). Yet water management, drinking water supply and sanitation, and hygiene are also critical for the achievement of MDGs 4, 5 and 6, and for sustaining the achievements thus far to reduce child mortality, improve maternal health and reduce the burden of malaria.

As public health interventions, water management, drinking water supply and sanitation, and hygiene can form the primary basis for prevention against a significant majority of the global burden of water-related disease. This includes diarrhoeal diseases, arsenic and fluoride poisoning, intestinal nematode infections, malnutrition, trachoma, schistosomiasis, malaria, onchocerciasis, dracunculiasis, Japanese encephalitis, lymphatic filariasis and dengue. However, efforts to implement successful WaSH public health interventions to combat these diseases are complicated by the fact that each is associated with a variety of economic, societal and environmental driving forces. Responsibilities within governments are fragmented over a number of entities at different levels, and coordination among these and across sectors continues to be a challenge. Moreover, large knowledge gaps currently prevent adequate prediction of trends and regional hotspots. Nevertheless, illustrative examples reveal how these interventions can contribute to reducing or preventing disease.

4.1.1 Trends and hotspots

Identifying trends and hotspots around the interface of water and health is extremely difficult, due to challenges in monitoring and reporting, a lack of information on environmental health determinants, and the interplay of non-environmental determinants on health. Nevertheless, available insights do provide a basis for effective action. Despite a lack of localized disease prevalence estimates, some diseases are clearly on the rise (such as cholera, see Box 4.1), and select reasons for these increases can be addressed. Three examples are provided below that illustrate the complex nature of disease risk, and highlight the ways in which strategies are already being investigated and implemented to combat these risks.

4.1.2 Drivers

The global drivers predicted to have the greatest effect on human health via the water environment include demography, agriculture, infrastructure and climate change.

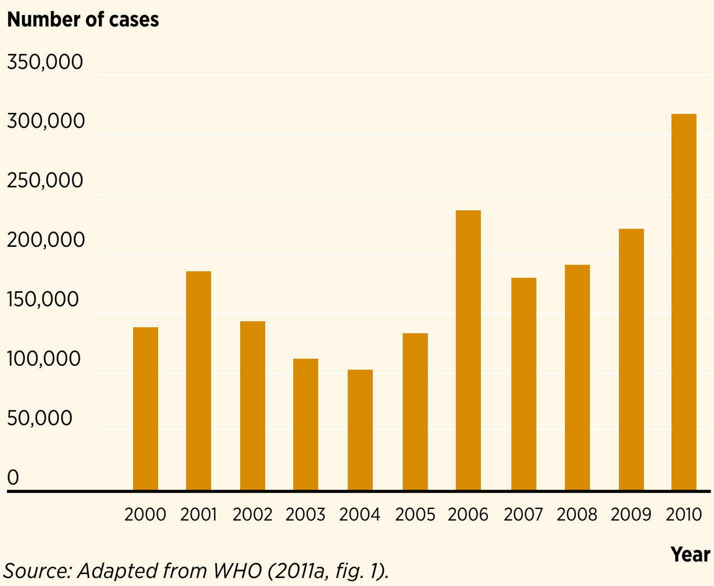
Population growth and urbanization can significantly impact human health through increasing water demands and increasing water pollution. Rising demand for water resources may contribute to water scarcity, with potential implications for reliability of drinking water access, water quality and hygiene. There will be a tendency for increased incidence of diseases transmitted in the absence of sufficient safe water for washing and personal hygiene, or when there is contact with contaminated water. These include diarrhoeal diseases, intestinal nematode infections and trachoma. Rapid population growth in urban or peri-urban areas that lack services for reliable provision of safe water, basic sanitation services or solid waste management can lead to increases in small-scale water storage (Bradley and Bos, 2010), water pollution and growing proportions of the population exposed to pathogens (WHO, 2007). Such situations amplify the risk for diseases such as diarrhoea, intestinal nematode infections, trachoma, schistosomiasis, dengue and lymphatic filariasis.

The accelerating process of global urbanization translates into increased exposure to poorly designed or managed water systems and poor access to hygiene and sanitation facilities in **public settings** (e.g. healthcare centres, schools, public offices). This results in an increased risk of disease outbreaks. Action to reduce this risk in public settings is a public health priority. The morbidity and mortality associated with healthcare-associated infections represents a loss of health-sector and household resources worldwide. Schools, particularly in rural and peri-urban areas, often lack drinking water, sanitation and hand-washing facilities. The resulting transmission of disease manifests as significant absenteeism. Public settings provide an opportunity to educate visitors about minimizing disease transmission with targeted messages and a 'model' safe environment, which can be emulated at home. National policies, standards, guidelines on safe practices, training and promotion can aim to reduce the

BOX 4.1

Cholera

Number of cholera cases reported to the World Health Organization between 2000 and 2010

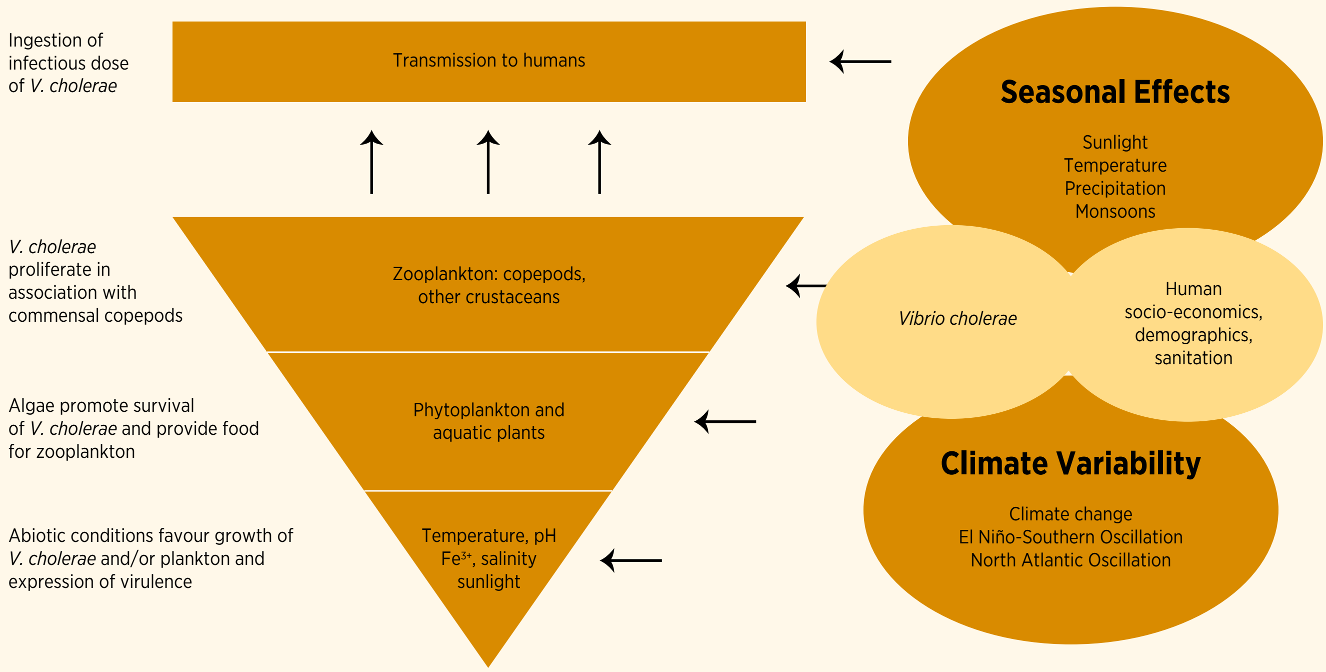


Source: Adapted from WHO (2011a, fig. 1).

Cholera is an acute diarrhoeal disease caused by the ingestion of food or water contaminated with the bacterium *Vibrio cholerae*. Every year, there are an estimated 3–5 million cholera cases and 100,000–120,000 deaths due to cholera. (WHO estimates that only 5–10% of cases are officially reported.) Moreover, the number of cholera cases continues to rise (see figure to the left): the number of cases reported to the World Health Organization (WHO) increased by 16% from 2008 to 2009, 43% from 2009 to 2010, and the overall increase for the decade 2000–2010 was 130% (WHO, 2010*a*). The massive increase in 2010 is largely due to the outbreak that began in Haiti in October 2010, following an earthquake in January 2010.

Cholera is endemic in regions with poor socio-economic conditions, rudimentary sanitary systems, absence of wastewater treatment and where public hygiene and safe drinking water is lacking (Huq et al., 1996). Specifically, cholera is endemic

Hierarchical model for environmental cholera transmission



Source: Lipp et al. (2002, fig. 1, p. 763, reproduced with permission from The American Society for Microbiology).

Up to 80% of cholera cases can be *treated* simply and successfully through administration of oral rehydration salts. *Prevention* of cholera, however, relies on the availability and use of safe water, improved sanitation, including wastewater treatment, and hygiene. Prevention strategies are also critical in averting or mitigating cholera outbreaks. In the case of the outbreak in Haiti, the country's public health response strategy, led by the Ministry of Public in many parts of Africa and Asia, and has more recently become endemic in the Americas. Risk factors in endemic regions can include proximity to surface waters, high population densities and low educational levels (Ali et al., 2002), while factors affecting *V. cholerae* include temperature, salinity, sunlight, pH, iron, and phytoplankton and zooplankton growth (Lipp et al., 2002). The figure below describes a hierarchical model for environmental cholera transmission. The risk of cholera outbreaks intensifies during humanitarian crises, such as conflicts and floods, and displacement of large populations. Typical at-risk areas include peri-urban slums without basic water and sanitation infrastructure, and refugee camps, where minimum requirements of safe water and sanitation are not met. In fact, the re-emergence of cholera has coincided with the increase in populations living in unsanitary conditions (Barrett et al., 1998). For example, the onset and spread of the cholera epidemic of 1991 in Peru are closely related to the deterioration in the drinking water supply, sanitation and health services brought by the economic crisis of the 1980s (Brandling-Bennett, Libel and Migliónico, 1994).

Health and Population and supported by WHO and other partners, has incorporated multiple health solutions to reduce the levels of morbidity and mortality due to cholera: delivery of soap for hand washing; delivery of chlorine and other products or devices for household water treatment; construction of latrines; improved hygiene in public places (such as markets, schools, healthcare facilities and prisons); and implementation of health education campaigns through various media including community mobilizers (WHO, 2010*b*). In fact, the availability of safe water supplies may prove to be more important for combating cholera than antibiotics or vaccines. A recent study showed that the provision of safe water might have averted 105,000 cholera cases (95% Confidence Interval 88,000–116,000) and 1,500 deaths (95% Confidence Interval 1,100–2,300) in Haiti between March and November of 2011 – more than the estimated individual effects of antibiotics or vaccines (Andrews and Basu, 2011). With increasing populations living in peri-urban slums and refugee camps, as well as increasing numbers of people exposed to the impacts of humanitarian crises, the risk from cholera will likely increase worldwide, reinforcing the need for safe drinking water, adequate sanitation and improved hygiene behaviour under these conditions.

number of infections associated with these settings (WHO, 2011*c*; WHO/UNICEF, 2009).

Agriculture is essential to food security and adequate nutrition; yet certain practices can adversely impact human health by increasing water withdrawals for irrigation, changing water regimes in agro-ecosystems, and increasing water pollution. Growth in agriculture and industry is currently reported to be the main cause of surface water and groundwater quality deterioration (WWAP, 2006). Poor agricultural practices can lead to pollution of surface water and groundwater with pesticides, pollutants, nutrients and sediments. Impacts also include increased breeding grounds for disease vectors and contamination of water supplies with pathogens from animal manure. Diseases that are likely to increase with agricultural expansion and intensification include diarrhoeal diseases, trachoma, schistosomiasis, lymphatic filariasis and malaria (Jiang et al., 1997; Nygard et al., 2004; Prüss and Mariotti, 2000; Rejmankova et al., 2006). Contaminated waters can also facilitate transmission of diarrhoeal diseases when wastewater (sewage) and excreta are used to irrigate or fertilize crops. This practice is employed increasingly in many peri-urban areas of the world, especially those in arid and semi-arid zones characterized by intense competition for water between agriculture and urban uses, and, combined with the changing nutritional habits of urban populations, poses a real health threat (Drechsel et al., 2010). Expansion of agriculture may also lead to deforestation, as regions seek to enlarge the areas available for agricultural practices. Deforestation can impact human health by removing the forest buffers that contribute to controlling non-point source pollutants from entering watercourses, increasing the concentration of pollutants downstream. Non-point source pollutants include nutrients, chemicals, sediments and pathogens, such as those that cause diarrhoeal disease. In addition to increasing water pollution, deforestation also affects disease rates by changing vector and host ecology and behaviour, potentially increasing the rates of malaria and onchocerciasis (Adjami et al., 2004; Walsh et al., 1993; Wilson et al., 2002).

The construction of **infrastructure**, including dams and irrigation projects, plays an important part in meeting demands for water. Yet while they contribute to food and energy and help manage the extremes of water, water resources infrastructure can also adversely impact human health. Dams and irrigation projects can, if not appropriately designed and managed, create breeding grounds for the black flies that spread onchocerciasis and the mosquitoes that spread malaria, lymphatic filariasis and Japanese encephalitis (Erlanger et al., 2005; Keiser et al., 2005*a*; Keiser et al., 2005*b*). These projects may also create habitats that encourage growth of the host snail of schistosomes (Molyneux et al., 2008).

BOX 4.2

Harmful algal blooms

Harmful algal blooms (HABs) are algae harmful to humans, plants or animals, as opposed to most algal species, which are nontoxic and constitute natural parts of marine and freshwater ecosystems. While HABs do not represent a dominant global disease burden, there is a trend of increasing bloom detection, which likely indicates a real increase in incidence as well as increased surveillance. The reasons for this growth are varied, and include natural mechanisms of species dispersal and anthropogenic causes, such as pollution, climate change and transport via ballast water (Granéli and Turner, 2006). Approximately 60,000 individual cases and clusters of human intoxication occur annually around the world (Van Dolah et al., 2001). Although the mechanisms by which HABs affect human health are not fully understood, government authorities are conducting monitoring for HABs and developing guidelines for public health action in order to mitigate their impact. For example, the US Environmental Protection Agency (EPA) has added specific HAB-related algae to its Drinking Water Contaminant Candidate List, which identifies organisms and toxins believed to be priorities for investigation. Direct control of HABs is much more difficult and controversial than mitigation, and strategies include mechanical, biological, chemical, genetic and environmental control. Conversely, prevention of HABs is currently hampered by a lack of understanding of the causes of HAB formation in many areas, as well as an inability to modify or control known determining factors. For example, increased inputs of nutrients from agricultural, domestic and industrial sources are a known cause for many HABs. Yet much of the nutrient input comes from non-point sources (Anderson et al., 2002), which are often difficult to control. The most effective strategies include controlling land use, maintaining landscape integrity, and implementing structural and non-structural practices for reducing nonpoint source pollution (e.g. stormwater detention ponds and improved infrastructure design) (Piehler, 2008). As the world's population continues to grow, its demands on coastal resources will most certainly increase, reinforcing the need to understand HAB phenomena and develop sound policies and practices.

Global climate change is expected to exacerbate current stresses on water resources from population growth and land use, and also to increase the frequency and severity of extreme weather and hydrological events (e.g. inland flooding). Higher water temperatures, increased precipitation intensity and longer periods of low flows are projected to exacerbate many forms of water pollution and increase pressure on diseases such as malaria, schistosomiasis and diarrhoea (Bates et al., 2008; Koelle et al., 2005; Zhou et al., 2008). For example, climate has been found to influence cholera dynamics in Bangladesh (Bouma and Pascual, 2001; Colwell, 1996; Koelle et al., 2005; Pascual et al., 2000; Rodo et al., 2002;), Peru (Colwell, 1996; Speelmon et al., 2000) and five countries in Africa (Constantin de Magny et al., 2007). More frequent heavy rainfalls will also likely overload the capacity of sewer systems, resulting in untreated

BOX 4.3

Dengue

In 2004, approximately 9 million people contracted the febrile illness dengue (WHO, 2008). Global incidence continues to rise with approximately 2.5 billion people now at risk. There is no drug or vaccine for the virus; therefore, safe drinking water and sanitation are key interventions for this disease. Dengue is transmitted by two mosquito species, *Aedes aegypti* and *Aedes albopictus*, which breed in temporary water-storage containers in the domestic environment. Thus, safe storage of household water supplies is a critical component of dengue prevention, especially in areas that practice rainwater harvesting and use large household water storage vessels (Mariappan et al., 2008). Household water containers can be fitted with screens or proper lids to exclude mosquitoes, but their scrupulous maintenance and consistent use is hard to achieve. Covers treated with insecticide can further reduce densities of dengue vectors and potentially impact dengue transmission (Kroeger et al., 2006; Seng et al., 2008). Water containers can also be eliminated entirely with piped water supplies. However, the extension of piped water supplies to villages has expanded the range of dengue from urban to rural environments, where the unreliability of piped water supplies has forced people to store water in their homes for longer periods of time when previously they relied on well water (e.g. Nguyen et al., 2011). In effect, an integrated approach, combining household water treatment and safe storage, is necessary for the reduction of diarrhoeal as well as other water-associated diseases (e.g. dengue and malaria) in the households and communities of developing and developed countries.

sewage, with its associated pathogens, flowing into water bodies, with a tendency towards increases in diarrhoeal diseases, including outbreaks.

The Vision 2030 study (WHO/DFID, 2009) advocates the need to integrate resilience of water and sanitation infrastructure into the planning, policy-making and management of drinking water and sanitation, to adapt and cope effectively with the potential adverse impacts of climate variability. A major paradigm shift from the 'business-as-usual' approaches in drinking water and sanitation systems and services is essential in order to adapt to climate change and transform threats into opportunities. Optimizing resilience of water and sanitation infrastructure will maximize health benefits of future investments, and ensure that drinking water and sanitation infrastructure remain functional in the face of climate change-induced extreme weather events.

There is an urgent need to improve our understanding of the dynamics relating to the ways in which each of these drivers affect human health: the complex set of factors that generate them, the characteristics of populations that increase their vulnerability, and the identification of populations most at risk for each of these threats (Myers and Patz, 2009). Such improved understanding would also provide a basis for measures aimed at reducing health risks from water-related diseases, and would thereby aid resource managers and policy-makers in determining the health impacts associated with their decisions, and allow aid organizations to target their resources more effectively.

4.1.3 Options and consequences

Key messages

1. The global drivers predicted to have the greatest effect on disease rates via the water environment are *population growth and urbanization, agriculture, infrastructure and global climate change*. Trends in these drivers directly and indirectly impact the global burden of disease, largely adversely, and increase the overall uncertainty in future human health.
2. There are numerous non-water-related environmental determinants of health, as well as non-environmental determinants of health that confound the attribution of health trends and hotspots to water.
3. By outlining the environment-health nexus for each of the major water-related disease groups, five key solutions were identified: *access to safe drinking water, access to basic sanitation, improved hygiene, environmental management,* and the *use of health impact assessments.* Implementation of these actions serves to reduce the burden of multiple diseases and improve the quality of life of billions of individuals.
4. In-depth studies targeting the future impacts of powerful underlying drivers, such as those identified in this report, are required to more accurately identify the risks and opportunities related to water and health. These studies would evaluate the complex interactions around population, development and urbanization, similar to The 2030 Vision Study, which determined the major risks, uncertainties and opportunities related to the resilience of water supply and sanitation in the face of climate change.
5. Protection of human health requires collaboration among multiple sectors, including actors and stakeholders in non-water and non-health sectors.

Determining how past and present (and indeed projected future) driving forces contribute to the burden of disease provides a basis for the development of the aforementioned primary prevention strategies. Outlining this pathway for each of the major water-associated diseases leads to the formulation of five key actions for combating the burdens they cause: access to safe drinking water, access to basic sanitation, improved hygiene, environmental management and the use of health impact assessments. Implementation of these actions would contribute to reducing the burdens of diverse diseases and improve the quality of life for billions of individuals.

This fact was reaffirmed in May 2011, when the 64th World Health Assembly unanimously adopted resolutions on 'drinking-water, sanitation and health' (WHA, 2011b*)* and 'cholera: mechanism for prevention and control' (WHA, 2011*a*). These resolutions established the policy framework for WHO, its sister UN agencies – in particular UNICEF, and the ministries of health of its 193 Member States –to take determined action to promote access to safe and clean drinking water, and basic sanitation and hygiene practices. Member States were urged to re-affirm a strong role for drinking water, sanitation and hygiene considerations in their national public health strategies.

Actions for combating the major water-related disease burdens can be pursued at a variety of different levels:

- The formulation of national policies and the creation of institutional frameworks: efforts in these areas can result in an enabling environment for universal and efficient provision of safe drinking water and sanitation services.
- Networking: bringing together professionals to share information and experiences can play a key role in combating the water-related disease burden. Examples of such networks include WHO-hosted international networks (e.g. the Drinking-water Regulators Network and the Small Community Water Supplies Management Network), the WHO/UNICEF Network on Household Water Treatment and Safe Storage, and the WHO/IWA Network on Operation and Maintenance.
- Normative capacities: efforts to strengthen normative capacities can bolster disease prevention, for example, the fourth edition of the *WHO Drinking Water Quality Guidelines* (WHO, 2011*b*) and subsequent water safety planning approach for implementation (WHO/IWA, 2009).
- Monitoring and surveillance: global monitoring by the WHO/UNICEF Joint Monitoring Programme on Water Supply and Sanitation (JMP) and by the UN-Water/WHO Global Analysis and Assessment of Sanitation and Drinking-water (GLAAS) guides policies, resource allocation and actions to achieve the MDG target, and provides a platform for the development of indicators and targets for post-2015 monitoring, linked to criteria for the human right to water and sanitation (WHO/UNICEF, 2011).

Health impact assessments (HIAs) can be used to objectively evaluate the potential health effects of a water policy or project before it is implemented or constructed, and provide recommendations to increase positive health outcomes and minimize adverse health outcomes as part of a public health management plan. The HIA framework is used to comprehensively address public health issues in the decision-making process for development planning that fall outside of traditional public health arenas: transportation, agriculture, land use, energy and infrastructure. Taking public health consequences into consideration 'upstream' as part of the early planning process creates a window of opportunity for design and management interventions that cannot be deployed once the project is operational. It also fosters an intersectoral approach to reduced pathogen transmission and prevents the subsequent transfer of 'hidden costs' to the health sector.

Determining how past, present and predicted future driving forces contribute to the water-related disease burden has also led to the identification of major risks, uncertainties and opportunities. These include the risk of increasing failures of aging water infrastructure and, conversely, the opportunity to increase the overall impact of water resources and water supply and sanitation infrastructure through improved management. The impact of such actions improves use of limited financial resources, thereby enhancing both access to water and sanitation, and associated service quality, and leads indirectly to improvements in wider health indicators such as malnutrition.

Additional in-depth studies are required to more accurately identify the risks and opportunities related to water and health. The 2030 Vision Study, commissioned by the United Kingdom Department for International Development (DFID) and WHO, performed such an analysis of the major risks, uncertainties and opportunities related to the resilience of water supply and sanitation in the face of climate change (WHO/DFID, 2009). The study brought together evidence from projections on climate change, trends in technology application, and developing knowledge about drinking water and sanitation adaptability and resilience, to identify key policy, planning and operational changes required to adapt to climate change, particularly in low and middle-income countries where access to water supply and sanitation services are more limited. Five key conclusions resulted from this study:

1. Climate change is widely perceived as a threat rather than an opportunity. There may be significant overall benefits to health and development in adapting to climate change.
2. Major changes in policy and planning are needed if ongoing and future investments are not to be wasted.
3. Potential adaptive capacity is high but rarely achieved. Resilience needs to be integrated into drinking water and sanitation management to cope with present climate variability. It will be critical in controlling adverse impacts of future variability.
4. Although some of the climate trends at regional levels are uncertain, there is sufficient knowledge to inform urgent and prudent changes in policy and planning in most regions.
5. There are important gaps in our knowledge that already or soon will impede effective action. Targeted research is urgently needed to fill gaps in

technology and basic information, to develop simple tools, and to provide regional information on climate change. (WHO/DFID, 2009, p. 3)

The relationship between the drivers of water-related diseases and human health is complex. Thus, protection of human health requires collaboration among multiple sectors. Policies and projects in non-water or non-health sectors should reflect the links between water management and health in decision-making processes in order to avoid unintended adverse public health consequences, as well as to increase overall benefits. To do so requires the engagement of health professionals and institutions.

In the case of drinking water quality management, there is increasing recognition that addressing the complex root causes of water contamination is a more effective and sustainable approach then reacting to problems after they occur. The fourth edition of the *Guidelines for Drinking Water Quality* (WHO, 2011*b*) emphasizes the need for collaboration between all stakeholders, including land users or householders who may discharge industrial, agricultural or domestic waste into a catchment area; policy-makers from various ministries overseeing the implementation and enforcement of environmental regulations; practitioners delivering water; and consumers at the tap. This preventive and collaborative water-safety planning approach has demonstrated benefits, including cost-savings and sustainable improvements in water quality. Experience also shows, most recently in South and East Asia, that while progress is being made, implementing such a 'no short-cut' approach remains a challenge. Each risk management solution needs to be tailor-made to the water supply in question, and demands that key stakeholders become engaged and committed to a common goal.

4.2 Water and gender

Among the many water-related challenges worldwide, the crisis of scarcity, deteriorating water quality, the linkages between water and food security, and the need for improved governance are the most significant in the context of gender differences in access to and control over water resources. These challenges are expected to become more intense in the future, due to the growing uncertainty and risk associated with the availability and quality of freshwater resources, arising from increasing demand for various uses, climate variability and natural disasters.

"In the case of drinking water quality management, there is increasing recognition that addressing the complex root causes of water contamination is a more effective and sustainable approach then reacting to problems after they occur."

Water is used for a wide range of socio-economic activities including public health, agriculture, energy and industry. Unsustainable and short-term decisions taken in the context of these activities have an impact on water resources, with different social and economic consequences for men and women in the community. Over the longer term, scarcity created at the local level as a result of this crisis is likely to increase inequity within local communities with regard to access and control over local water resources, affecting poor women the most.

Decisions related to water sharing, water allocation and water distribution between different uses and across regions are most often made at higher levels where economic and political considerations generally play a more important role than social concerns. These decisions impact the water resources locally available to communities, who are likely to lose access to the very resources that sustain their livelihoods and fulfil their needs. Rural women often rely upon common water resources such as small water bodies, ponds and streams to meet their water needs, but in many regions these sources have been eroded or have disappeared due to changes in land use, or have been appropriated by the state or industry for development needs or to supply water to urban areas.

Water has different values for different uses and purposes, and the same source of water can be used for social as well as economic purposes. Social and environmental valuation is more prevalent at the local level, where water sources may be designated for different uses such as drinking, common uses such as bathing and washing depending on the quality of water, or regarded as sacred for religious purposes. Water that has been valued as an economic good, such as irrigation water supplied through an irrigation scheme, also has a social value for local communities, especially for women, who may use the same irrigation water source for both domestic and farming purposes. Opportunities for improving access to water for women and improving their water security can be found by analysing water values through a gender lens.

Water policies based on broad, generalized perspectives are more likely to omit local knowledge, and social and gender dimensions and their implications. Recognizing the various purposes for which these local water resources are used by different groups of men and women in the community would help to successfully integrate gender considerations, not only in water resource management, but also in sectors such as urban water supply, agriculture, industry and energy that depend upon water resources, and which often conflict over water allocations and their demand for freshwater resources. By working together in partnership with these sectors, decision-makers in government bodies, private sector and civil society can understand and address the potential synergies and trade-offs that occur when providing access to different groups of men and women in local communities. This approach would help to anticipate risks and uncertainties and plan for safeguards to protect the most vulnerable groups in the community.

There is enough evidence to show that integrating a gender-sensitive approach to development can have a positive impact on the effectiveness and sustainability of water interventions and on the conservation of water resources. Involving both men and women in the design and implementation of interventions leads to effective new solutions to water problems; helps governments to avoid poor investments and expensive mistakes; makes projects more sustainable; ensures that infrastructure development yields the maximum social and economic returns; and furthers development goals, such as reducing hunger, child mortality and improving gender equality (Oxfam, 2005, 2007).

Although it is true that many socially constructed barriers need to be overcome in order to facilitate the involvement of both men and women in decision-making and management of water resources, it is also true that traditional gender roles have often been challenged successfully by developing women's capacities to manage water interventions, and providing them with opportunities to play leadership roles and improve their economic conditions. However, these successes are often limited to the local context, as the larger issues, such as providing water rights to women, are governed by external factors, which are not only outside the purview of these interventions, but involve traditional, cultural and political realities that are difficult to change in the short term, and require long-term commitment from policy-makers, governments, politicians and advocacy groups.

Over many decades, the United Nations has made significant progress in advancing gender equality, including through landmark agreements such as the Beijing Declaration and Platform for Action, and the Convention on the Elimination of All Forms of Discrimination against Women (CEDAW), and the setting up of UN Women to accelerate progress in achieving gender equality and women's empowerment. Water and Gender is listed as one of UN-Water's Thematic Priority Areas in its 2010–2011 Work Programme, while the promotion of gender equality is one of UNESCO's two global priorities for 2008–2013.

4.3 Ecosystem health

Trends in ecosystems and the benefits they deliver indicate the presence of a serious ecological imbalance. This instability and degradation in ecosystems increases uncertainty and amplifies risk. Tipping points in ecosystems, beyond which damage accelerates and becomes irreversible, are being rapidly approached, and involve high risk and potentially major socio-economic impacts. There is some good news: the current situation has resulted in increasing attention to ecosystems, some successful responses, and a narrowing divide between water, ecosystems, environment, biodiversity and human development interests. Ecosystems offer solutions to achieving water-related objectives and reducing uncertainty and risk; the task is to mainstream and upscale them.

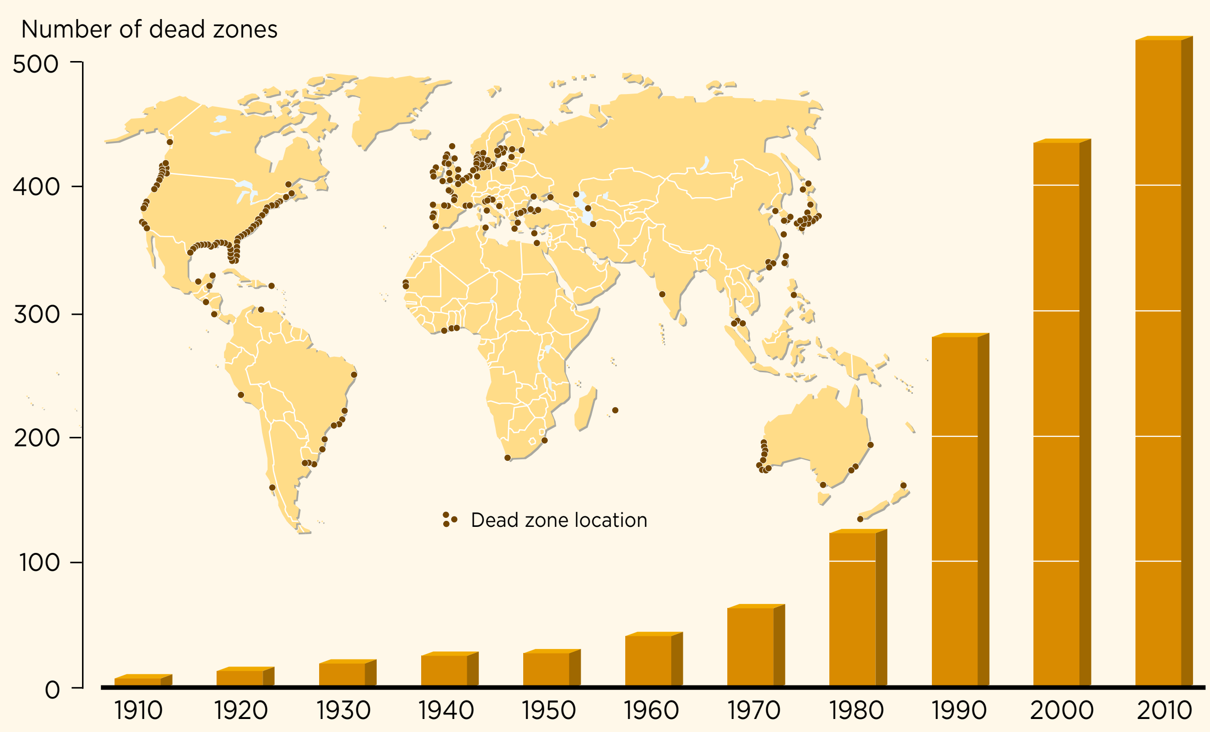
Ecosystems deliver multiple benefits (or services) that are essential for sustainable development. Many of these key services are derived directly from water, and all are underpinned by it. Trends in ecosystem health, therefore, indicate trends in the delivery of these overall benefits and provide a key indicator of whether human society is in or out of balance with water. And the trends in ecosystems, including the life they support, are indicating clearly and unambiguously that things are out of balance.

WWDR2 (WWAP, 2006) and WWDR3 (WWAP, 2009) reviewed the principal pressures and impacts on freshwater ecosystems. The key direct water-related drivers involved are ecosystem conversion (e.g. drainage and conversion of wetlands); fragmentation (e.g. dams and reservoirs); and degradation (principally, water availability/flow and water quality/pollution). The indirect drivers responsible for these arise from the social (including demographic) and economic changes associated with development, and the fact that most human needs and activities directly or indirectly impact limited water resources. At global and regional scales, the nature of these drivers remains largely unchanged. Although there are some shifts in their relative weight, most drivers show increasing negative trends overall.

Considering the trends in these drivers, the recent overall picture of ecosystem health is unsurprisingly one of escalating degradation. The increasing negative trend presented in WWDR2 and WWDR3, and comprehensively outlined by the Millennium Ecosystem Assessment (MA, 2005*a*), is maintained based on several recent detailed assessments; these include *Global Environment Outlook 4* (UNEP, 2007), *Global Biodiversity Outlook 3* (CBD, 2010*a*), and regional assessments such as those undertaken for Africa (UNEP, 2008). A review of progress towards the 2010 biodiversity target for inland waters concluded that the 2010 target and subtargets for inland waters biodiversity have not been achieved; the drivers of biodiversity loss remain unchanged and are all escalating; excessive nutrient loading has emerged as an important direct driver of ecosystem change in inland (and coastal) waters (Figure 4.1), and groundwater pollution remains a major concern; the surface water and groundwater portions of the water cycle have been subjected to massive changes by direct human use on local,

FIGURE 4.1

Nutrient loading in inland and coastal waters



Note: The number of observed 'dead zones', coastal sea areas where water oxygen levels have dropped too low to support most marine life, has roughly doubled each decade since the 1960s. Many are concentrated near the estuaries of major rivers, and result from the buildup of nutrients, largely carried from inland agricultural areas where fertilizers are washed into watercourses. The nutrients promote the growth of algae that die and decompose on the seabed, depleting the water of oxygen and threatening fisheries, livelihoods and tourism.
Source: CBD (2010a, fig. 15, p. 60).

regional and continental scales; and ecological sustainability of water available for abstraction is giving alarm signs (Box 4.4). Although progress has been made in policy and practical responses (e.g. designation of protected areas), the rate of increase is slowing, and most other indicators show continuing or often accelerating declines (Butchart et al., 2010). While protected wetland areas are increasing, most wetland sites are degrading (CBD, 2010*b*).

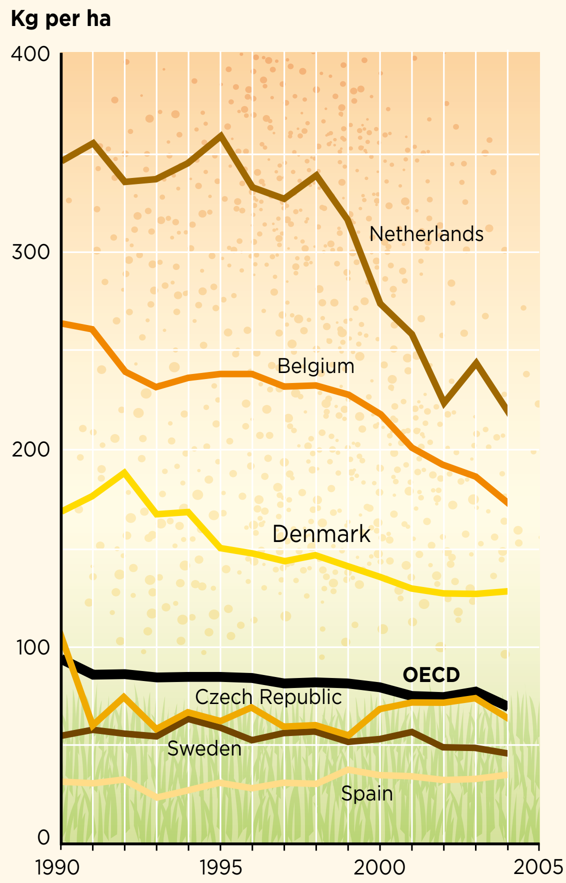
Some positive trends in developed regions – for example, improvements in managing nutrient loads (Figure 4.2), wetlands restoration, or a slowing or reversal of biodiversity loss – are offset by accelerated degradation in developing countries. An underlying problem is that rich nations are tending to maintain or increase their consumption of natural resources (WWF, 2010), but are exporting their footprints to producer, and typically, poorer, nations. For example, 62% of the United Kingdom's water footprint is virtual water embedded in agricultural commodities and products imported from other countries – 38% originates from domestic water resources – (Chapagain and Orr, 2008). In addition, much of the progress in pollution control in rich countries is attributable to the shift of industrial production elsewhere, for example, to China. This is particularly the case for water-related impacts, including through trade in virtual water. Notably, this also transfers uncertainty and risk to developing nations less prepared to deal with these impacts. Until richer consumers recognize and take responsibility for their global footprint, society shall continue to address the symptoms of the problem as a distraction from tackling its root cause.

There is ample evidence that humans are over-consuming natural resources overall at an unsustainable rate. Various estimates indicate that, based on business as usual, approximately 3.5 planet Earths would be needed to sustain a global population achieving the current lifestyle of the average European or North American. Importantly, the sustainability of water resources is a key subset of this dilemma. Recent studies suggest that the planetary limits of sustainable water may have already been reached or exceeded (Box 4.4). 'Hotspots' for ecosystem service degradation have not been systematically mapped, as such, but they correlate closely with areas of water stress (see Section 4.6) and high pollution loads (Figure 4.1). Rapid development, high population density and growth, industrialization, and to some extent limited water availability characterize the locations of the most impacted ecosystems.

'There is often an assumption that useable water in nature can be readily accessed and moved around at will. For example, many governments have ambitious plans to move massive volumes of water from water-rich to water-poor river basins' (Molden, 2009, p. 116). The consequences of these inter-basin water transfers on ecosystem health remain unclear, but they are likely to be immense. Water management also often focuses on surface water and groundwater to the detriment of ecosystems and their role in the water cycle. There needs to be broader recognition of the

FIGURE 4.2

Nitrogen balance in Europe



Note: The average nitrogen balance per ha of agricultural land (the amount of nitrogen added to land as fertilizers, compared with the amount used up by crops and pasture) for selected European countries. The reduction over time in some countries implies improved efficiency in the use of fertilizers, and therefore a reduced risk of damage to biodiversity through nutrient runoff.
Source: CBD (2010a, fig. 16, p. 61).

importance of conserving and restoring soil moisture, underpinned by soil ecosystem health, and the relationship between ground vegetation cover and local and regional humidity. Policy-makers and managers need to understand that ecosystems do not consume water – they supply and recycle it – and water taken from ecosystems unsustainably reduces their ability to deliver the benefits that society needs.

TEEB (2009) states that ecosystem loss and degradation does not always result in an immediately detectable or proportional response in terms of lost ecosystem services. Instead, a 'tipping point' may be reached, at which rapid and catastrophic collapse occurs following a period of apparent stability (e.g. Lenton et al., 2008). This potentially reverses sustainability and progress towards human welfare. The poor usually face

BOX 4.4

Have the global limits of water sustainability already been reached?

Based on an assessment of what the planet's ecosystem can sustainably supply, Rockström et al. (2009*a*) suggest that safe and sustainable consumption of 'blue water' sources (evaporation and transpiration from rivers, lakes, groundwater reservoirs and irrigation) should not exceed 4,000 km^3 per year. At present, blue water consumption is estimated at 2,600 km^3 per year. But Molden (2009) notes that, based on a wider review of studies on the global supply and demand of water, the 4,000 km^3 limit may be too high. These studies suggest that society is close to approaching the global limit of sustainable availability of water.

But distribution and consumption of water are uneven. The limits to sustainable water abstraction are already surpassed in many regions. For example, there is little or no additional stream flow or groundwater for further development in the Murray–Darling River in Australia, the Yellow River in China, the Indus in Pakistan and India, the Amu and Syr Darya in Central Asia, the Nile River, the Colorado River in the United States of America and Mexico, and in most of the Middle East. Many of these are important food-producing areas. The stress is reflected in ecosystem health, where all of these basins suffer from excessive pollution, river desiccation, competition for supplies and other ecosystem degradation (Molden, 2009). Globally, a strikingly small fraction of the world's rivers remain unaffected by humans, with the majority of river basins now exhibiting similar signs of stress (Vörösmarty et al., 2010).

BOX 4.5

Ecosystem tipping points: Theory or reality?

Deforestation can be seen as a mechanism that leads to decreasing regional rainfall through the loss of cloud-forming evapotranspiration from the forest. Local climate then becomes drier, thereby accelerating ecosystem change. In the Amazon, for example, an apparently moderate deforestation of 20% could mean that a tipping point is reached, beyond which forest ecosystems would collapse across the entire basin (World Bank, 2010*a*). This would have devastating impacts on water security and other ecosystem services that would reach far beyond the Amazon basin itself, including impacts on regional agriculture and global carbon storage.[1] Unfortunately, Amazon deforestation is already at approximately 18%.

Intact tropical forests of South America shifted from buffering the increase in atmospheric carbon dioxide to accelerating it during recent drought events; this was not compensated by recovery in non-drought years. If drought events continue, whether through climate change, deforestation or direct water use, the era of intact Amazon forests buffering the increase in atmospheric carbon dioxide may have passed (Lewis et al., 2011).

Nkem et al. (2009) provide evidence that these tipping points are being reached or surpassed in reality, as evidenced through some national reports to the UNFCCC, particularly for Central America. These suggest that the impacts of deforestation are already affecting water supply, to the extent of undermining, for example, sustainable hydropower. The countries surveyed also very clearly see the climate change-water-forest nexus as one of managing uncertainty and risk.

Tipping points triggered by multiple stressors go beyond just water and carbon. Rockstrom et al. (2009*b*) identify nine planetary boundaries beyond which ecosystems should not pass: climate change (greenhouse gas levels); ocean acidification; stratospheric ozone; nitrogen and phosphorus loads (cycling); global freshwater use; land-system change; the rate of loss of biodiversity, for which quantified limits are identified; and chemical pollution and atmospheric aerosol loading (which await metrics). They estimate that humanity has already transgressed three planetary boundaries: climate change, rate of biodiversity loss and the global nitrogen cycle (and note earlier that freshwater use is near or may have also exceeded the limits). 'The social impacts of transgressing boundaries will be a function of the social–ecological resilience of the affected societies. ... The proposed concept of "planetary boundaries" lays the groundwork for shifting our approach to governance and management, away from the essentially sectoral analyses of limits to growth aimed at minimizing negative externalities, toward the estimation [and management] of the safe space for human development' (Rockström et al., 2009*b*).

BOX 4.6

Trends in wetlands in China: Reversing losses to restore benefits

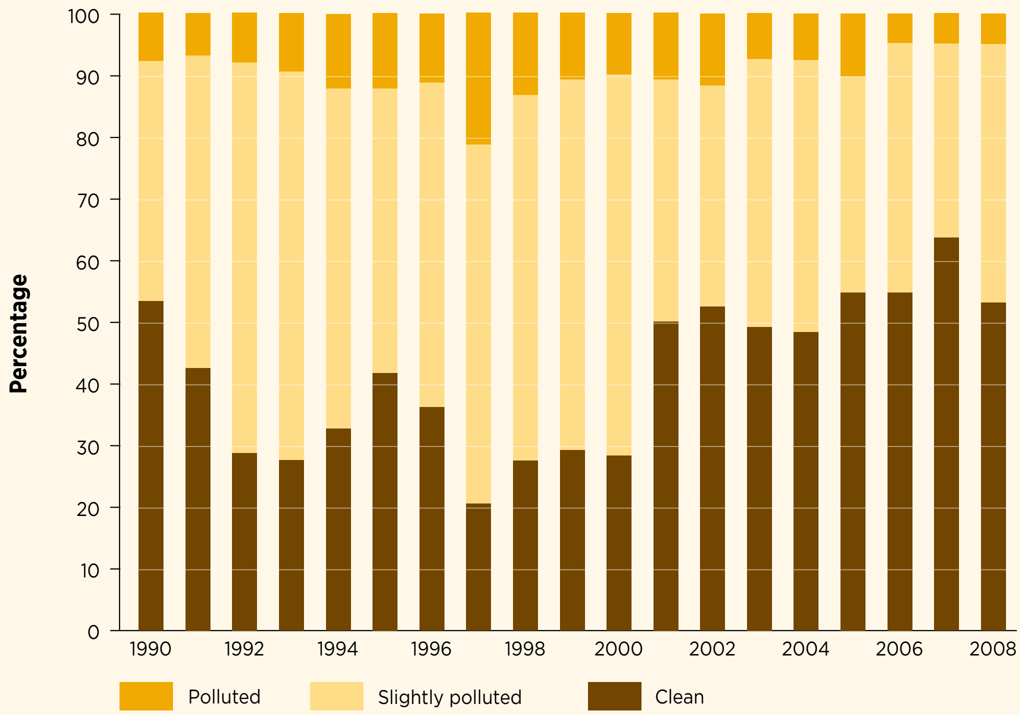
There is evidence of wholesale shifts in the right direction. For example, China's remarkable economic growth has unsurprisingly resulted in serious environmental problems, in particular rapid wetland degradation and loss, serious water shortages in the north, and wastewater pollution across the country. One report states that over 30% of natural wetland area may have been lost in only 10 years from 1990 to 2000 (Cyranoski, 2009). This is one of the highest rates of natural habitat loss recorded, outstripping trends in global forest loss, but is notably typical of the impacts of development. Where data exist they show even more extensive wetlands loss in OECD countries; for example, over 90% for New Zealand (Ausseil et al., 2008). However, wetland policies have changed in China, including shifts towards major rehabilitation efforts. A recent review suggests that in the five years post 2000, the wetland area in China has stabilized, possibly even increasing slightly (Xu et al., 2009). The driving force for this shift in policy has been recognition of the value of water-related wetland ecosystem services and the need to restore these as cost-effective solutions to water management problems.

the earliest and most severe impacts of such changes, but ultimately all societies and communities would suffer as a result (CBD, 2010*a*) (Box 4.5).

One useful development is growing attention to the need to integrate available knowledge and datasets to better explain and illuminate the interdependency of water, ecosystems and humans. The aforementioned reviews of trends in environment, ecosystems and biodiversity continue a shift in this direction, but largely through interpretation of trends in numerous subject areas independently. The most significant advances are now likely to emerge from approaches that better integrate different datasets and knowledge sources. For example, Vörösmarty et al. (2010) used data depicting 23 stressors (drivers), grouped into four major themes representing environmental impacts (catchment disturbance, pollution, water resource development and biotic factors), to assess a 'cumulative threat framework'. The results show that nearly 80% of the world's population is exposed to high levels of threat to water security, based on figures for the year 2000, implying a much greater level of risk than previous assessments.

FIGURE 4.3

Since 1997, the proportion of river basins in Malaysia classified as clean has been increasing



Source: CBD (2010a, fig. 11, p. 43).

Assessments of global or regional trends disguise good progress made at local and national scales. While water quality overall continues to deteriorate, there are signs of several pollutants coming under control through effective management measures (Figure 4.3), although non-point source pollution, particularly from agriculture, remains challenging in almost all areas. One positive trend is the emergence of more widespread attention to, and practical examples of, ecosystem-based approaches to achieving water management objectives. These approaches have yet to be upscaled and mainstreamed to attain the necessary impact on achieving global benefits, but there are promising signs (Box 4.6).

4.4 Water-related hazard risk

Water-related hazards form a subset of natural hazards; the most significant ones include floods, mudslides, storms and related ocean storm surge, heat waves, cold spells, droughts and waterborne diseases. Most disasters are caused by a combination of hazards, some related to water and other of geological and biological origin. Such events include those triggered by earthquakes, such as tsunamis, landslides that dam rivers, breakage of levees and dams, as well as glacier lake outbursts, coastal flooding associated with abnormal or rising sea levels, and epidemics and pest outbreaks associated with too little or too much water.

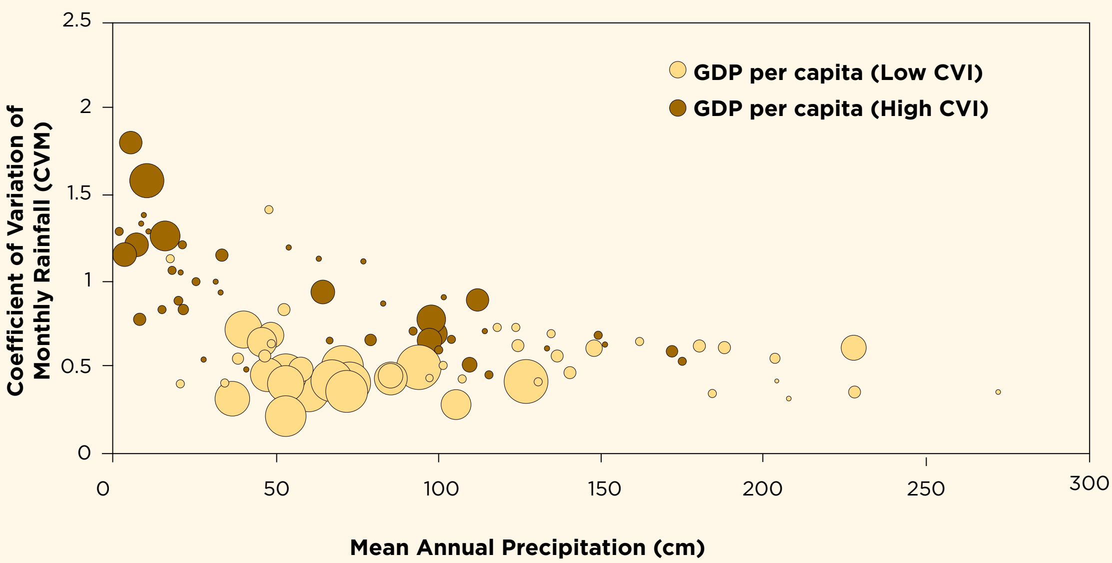
Water-related hazards account for 90% of all natural hazards, and their frequency and intensity is generally rising. 'Some 373 natural disasters killed over 296,800 people in 2010, affecting nearly 208 million others and costing nearly US$110 billion' (UN, 2011).

One water-related hazard that seldom makes it into the impacts statistics is drought. According to the United Nations *Global Assessment Report*, since 1900 more than 11 million people have died as a consequence of drought and more than 2 billion have been affected by drought, more than any other physical hazard (UNISDR, 2011). However, these figures are probably lower than the real total as few countries systematically report and record drought losses and impacts. According to same report, countries that do, such as the United States of America (USA), only report insured losses.

Disasters caused by water-related hazards have taken a toll not just on individual lives and livelihoods, but also on national development. Climate variability, which shows a strong correlation to the occurrence of

FIGURE 4.4

Climate variability has an impact on GDP



Note: This graph indicates that countries with a higher climate variability index (CVI) (dark brown dots) generally have lower GDP per capita (reflected in the size of the dots). The large dark brown dots here indicate the oil-producing states Kuwait, Oman and the United Arab Emirates
Source: Brown and Lall (2006, p. 310).

water-related hazards, has always existed and impacted development; in fact, countries with higher climate variability have generally been shown to have lower GDP per capita (Brown and Lall, 2006) (Figure 4.4). Between 1990 and 2000, natural disasters in several developing countries had caused damage representing between 2% and 15% of their annual GDP (World Bank, 2004; WWAP, 2009).

Due to climate change, it is expected that the frequency of certain natural hazards will increase (IPCC, 2007). While there is currently no evidence that climate change is directly responsible for increased losses associated with water-related hazards (Bouwer, 2011), given the increasing exposure and extremes, many countries are looking to reduce their risk to disasters as part of climate change adaptation (UNISDR, 2011).

A World Bank study released in 2010 examined the costs and benefits of specific prevention measures. The report examines government expenditures on prevention and finds that it to be generally lower than relief spending, which rises after a disaster and remains high for several subsequent years. But effective prevention depends not just on the amount, but on what funds are spent on. For example, Bangladesh reduced deaths from cyclones by spending modest sums on shelters, developing accurate weather forecasts, issuing warnings that people heeded, and arranging for their evacuation. All this cost less than building large-scale embankments that would have been less effective (World Bank, 2010*b*).

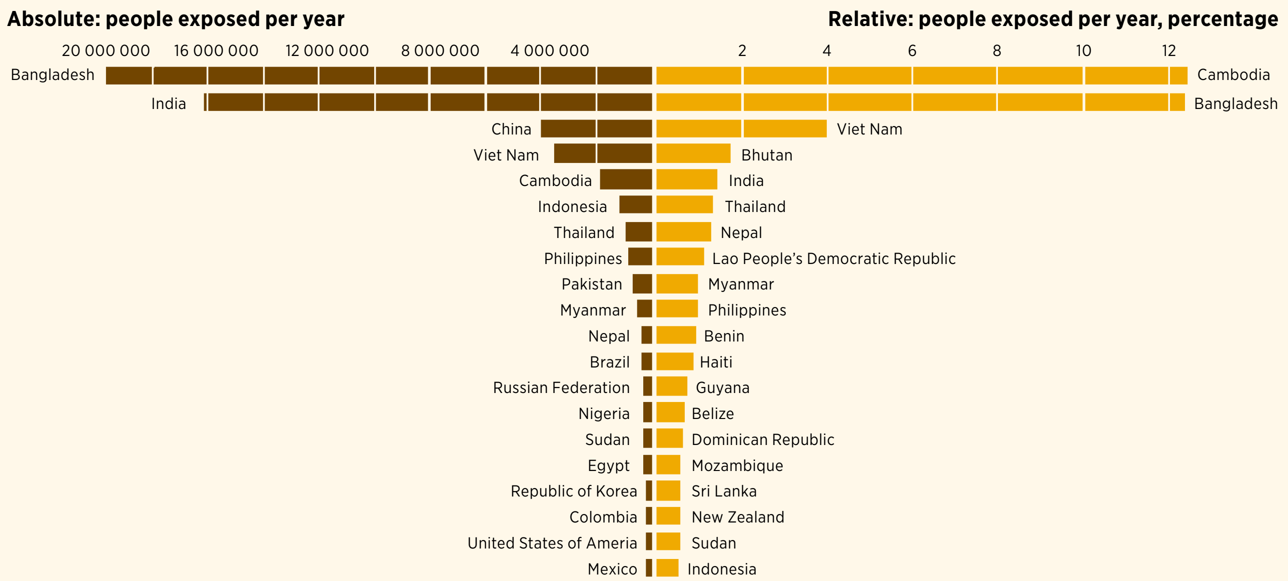
The increasing economic cost and toll of disasters should be a significant incentive for governments and humanitarian organizations to focus more attention on preparedness, prevention and addressing the root causes of vulnerability. In fact, increased donor interest in disaster prevention and risk reduction has not been matched by substantive amounts of new funding or new projects (Martin et al., 2006).

4.4.1 Trends in water-related hazard impacts and risk

Water-related disasters pose both direct impacts (e.g. damage to buildings, crops and infrastructure, and loss of life and property) and indirect impacts (e.g. losses in productivity and livelihoods, increased investment risk, indebtedness and human health impacts). The impacts of hurricanes, typhoons and cyclones depend on wind speed (category 1–5), where a storm strikes, how much flooding it causes, and the population density and quality of buildings and infrastructure in the affected area. Such storms cause impacts through high winds, tornadoes, storm surges (around 80–160 km wide across the coastline), storm

FIGURE 4.5

People exposed to floods



Source: UNISDR (2009, fig. 2.14, p. 36).

tides (tidally enhanced storm surges), and flooding associated with torrential rain. Along immediate coastlines, storm surges are the greatest threat to life and property. These types of storms can cause tremendous damage and loss of life in a matter of seconds.

Floods are one of the most frequent natural hazards, and they occur in almost every country. The severity of flash floods, river floods and urban floods depends on rainfall intensity, spatial distribution of rainfall, topography and surface conditions. Climate change is expected to increase the severity and frequency of flooding (IPCC, 2007). Drought affects more people globally than any other natural hazard (UNISDR, 2011). It does not destroy infrastructure or directly lead to human mortality, although famines may be triggered by drought (ultimately, however, mortality is due to a complex set of interactions surrounding food security). The 2011 famine in the Horn of Africa, which threatened the livelihood of more than 13.3 million people (UNOCHA, 2011), highlights the complex interaction between (and potential catastrophic consequences of) the climatic phenomenon resulting in low rainfall, the vulnerable pastoralist population with limited capacity to cope, and a political context of conflict.

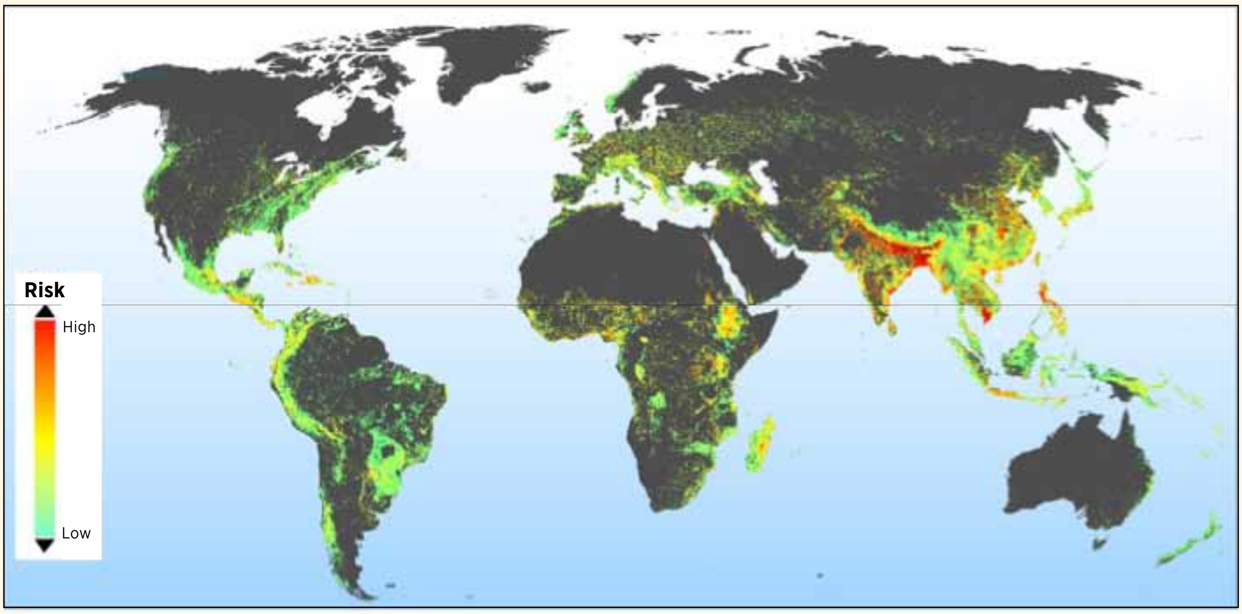
An observation of flood and drought 'risk patterns and trends at the global level allows a visualization of the major concentrations of risk and an identification of the geographic distribution of disaster risk across countries, trends over time and the major drivers of these patterns and trends' (UNISDR, 2011). Between 1970 and 2010 the world's population increased by 87% (from 3.7 billion to 6.9 billion) (UNISDR, 2011). During the same period, the annual average population exposed to flood increased by 112% (from 33.3 to 70.4 million per year) (UNISDR, 2011) (Figure 4.5).

'Countries in all regions have strengthened their capacities to reduce mortality risks associated with major weather-related hazards such as tropical cyclones and floods' (UNISDR, 2011, p. 18). Figure 4.6 shows an updated global distribution of mortality risk for three weather-related hazards (tropical cyclones, floods and landslides provoked by rains). The areas of highest risk visible in these maps correspond to areas where concentrations of vulnerable people are exposed to severe and frequent major hazards.

In contrast, countries have had a far more difficult time successfully addressing other risks. Economic loss risk

FIGURE 4.6

Hazard mortality risk (floods, tropical cyclones and precipitation-triggered landslides)



Source: Developed by the GAR team at UNISDR.

"Despite improvements in preventive efforts, disasters will still occur and preparedness and response capacity is essential."

to tropical cyclones and floods is trending up because the rapidly increasing exposure of economic assets is outstripping reductions in vulnerability (IPCC, 2007). Flood mortality risk is highest in rural areas with a dense and rapidly growing population and in countries with weak governance. Across all water-related hazards, countries with low GDP and weak governance tend to have drastically higher mortality risk than wealthier countries with strong governance (UNISDR, 2011).

Human health is both directly and indirectly impacted by water-related hazards. Outbreaks of waterborne diseases, such as cholera, can occur after disasters as a result of contaminated or inadequate water supplies, sometimes affecting thousands of people and causing many deaths. Outbreaks of vector-borne disease can also occur. For example, malaria epidemics have been shown to occur more frequently (in epidemic-prone areas) following dry periods associated with El Niño-Southern Oscillation – as documented in Colombia, Sri Lanka and Venezuela (PAHO, 2000).

In complex disasters where malnutrition, overcrowding and lack of the most basic sanitation are common, catastrophic outbreaks of gastroenteritis (caused by cholera or other diseases) have occurred (PAHO, 2000*a*). In Haiti in 2010, figures released by the government after the earthquake cite over 200,000 deaths, leaving a large and highly susceptible displaced population to confront hurricane season and potential disease outbreaks. In the aftermath of the earthquake disaster and flooding, the cholera outbreak resulted in the hospitalization of nearly 150,000 people, and left nearly 5,000 dead (USAID, 2011).

4.4.2 Behind the trends: Drivers of change

Understanding the underlying factors of risk for water-related hazards is the cornerstone of any effort to reduce risk and future impacts. The factors that have led to increased water-related disasters include natural pressures such as climate variability; management pressures such as lack of appropriate organizational systems and inappropriate land and water management; and social pressures such as population growth, assets and settlements in high-risk areas (Adikari and Yoshitani, 2009).

The increase in natural disaster losses over the past few decades is largely attributable to the increase in value of exposed assets, while anthropogenic climate change has not had a discernable impact on losses (Bouwer, 2011). By 2050, rising populations in flood-prone lands, climate change, deforestation, loss of wetlands and rising sea levels are expected to increase the number of people vulnerable to flood disaster to 2 billion (UNU, 2004).

4.4.3 Meeting the challenges ahead

Meeting the challenges associated with disasters caused by water-related hazards requires investment in and implementation of good disaster risk-reduction (DRR) practice. Despite improvements in preventive efforts, disasters will still occur and preparedness and response capacity is essential. Examples of best practices led by humanitarians, governments, water resources managers, the private sector and development agencies abound, although scaling these up to meet real needs remains a central challenge.

Disaster preparedness is improving; investments enabling earlier early warnings and actions are being undertaken (IFRC, 2009). For example, real investments in capacity and tools that incorporate weather and climate information into contingency planning and preparedness action are improving preparedness and response-saving resources, livelihoods and lives (Hellmuth et al., 2011). Investments in the capacity of communities and early warning systems in flood-prone areas, such as Mozambique, have resulted in better preparedness and response during flood events (GIZ, 2007). In Botswana, seasonal forecasts can provide useful indications of the likelihood of a malaria epidemic several months in advance (Hellmuth et al., 2009; Thomson et al., 2006).

To deal with escalating costs, governments are increasingly using insurance mechanisms and weather indexes to help them manage risk more effectively. These offer payouts when extreme weather events occur, offering the key advantage of speeding injections of cash, allowing for more timely responses. Another advantage is the ability to make concrete plans even before disaster strikes, knowing that funds will be available when needed. The Caribbean, Ethiopia, India, Malawi and Mexico provide examples of index insurance for disaster relief (Hellmuth et al., 2009).

Investment in DRR targets the root causes of vulnerability, which often stem from a combination of political, economic and social forces, as well as the impacts of highly variable rainfall. For example, in chronic food insecurity regions, programmes that complement food aid and build resilience and productivity are necessary to lift people out of poverty traps (Trench et al., 2007). Households, for example, may employ mitigation strategies to reduce vulnerability or the impact of risk by pooling risks through informal or formal insurance mechanisms.

With regard to extreme events, a recent study of 141 countries found that more women than men die from natural hazards, and that this disparity is linked most strongly to women's unequal socio-economic status. 'Where the socio-economic status of women is high, men and women will die in roughly equal numbers during and after natural hazards, whereas more women than men die (or die at a younger age) where the socio-economic status of women is low' (Neumayer and Plumper, 2007, p. 5). Mainstreaming gender into DRR offers an opportunity for improving disaster resilience and enhancing gender equality and sustainable development. However, introducing a gender perspective to DRR requires a change in attitude for policy-makers and implementers. Every citizen has a role to play in reducing disaster risk, but governments can create an enabling environment for women and men to participate in the effort. This would include communications and warning systems that can be accessed by women, and tapping into their knowledge and skills, which are crucial when managing and addressing risks (UNISDR et al., 2009; see Box 4.7).

Although investment in DRR, including water resources infrastructure, continues to lag, awareness is being raised and quantified evidence is being produced regarding its relative cost-effectiveness. Humanitarians have changed their approach over the past few decades, shifting from response and recovery to a more balanced approach that includes risk reduction: However, complementary capacity-building and financing mechanisms are sorely needed to fill the gap. Given that the cost and frequency of flood disasters is on the rise, investments in preparedness activities and associated infrastructure, flood plain policy development, effective watershed land use planning, flood forecasting and warning systems, and response mechanisms are essential to reducing risks and impacts (UNISDR, 2011). Comprehensive assessments of risks from water-related hazards are necessary, not only for improved understanding of changing risks, but also for better decision-making, planning and implementation of sustainable solutions.

Finally, because of rapid change and sometimes discontinuity in the combination of political, economic and social forces, future risks are unknown. Reflecting on scenarios describing possible futures can help decision-makers to take a longer-term view.

4.5 Impact of desertification on water resources

Poor and unsustainable land utilization and management practices are leading to desertification and land degradation around the world, increasing pressure on

BOX 4.7
Women in times of disaster

Women are usually responsible for children and the elderly; therefore the demands on them immediately prior to and during a disaster are very different from those of men. Such different demands are especially important to consider in the case of rapid onset disasters, when the time between receiving a warning and responding can be very limited. A report on *Mainstreaming Gender into Disaster Recovery and Reconstruction* (Dimitríjevics, 2007) provides some examples of disaster managers setting up childcare facilities on-site so that female staff who are impacted by a disaster can still work to assist others. This type of on-the-spot decision illustrates how routine contingency planning to provide childcare to women involved in early warning and emergency response could help more people. The example above also illustrates that knowledge, acceptance and respect for gender differences and strong social norms, can improve response as well as the planning and administration of relief items (UNISDR et al., 2009).

water resources and leading to water scarcity. Recent estimates indicate that nearly 2 billion ha of land worldwide – an area twice the size of China – are already seriously degraded, some irreversibly (FAO, 2008). Land degradation is increasing, with almost one-quarter of the global land area being degraded between 1981 and 2003. The emphasis on land degradation has focused on dryland areas, but humid areas are also experiencing a surprising level of global land degradation, more than initially thought (Bai et al., 2008).

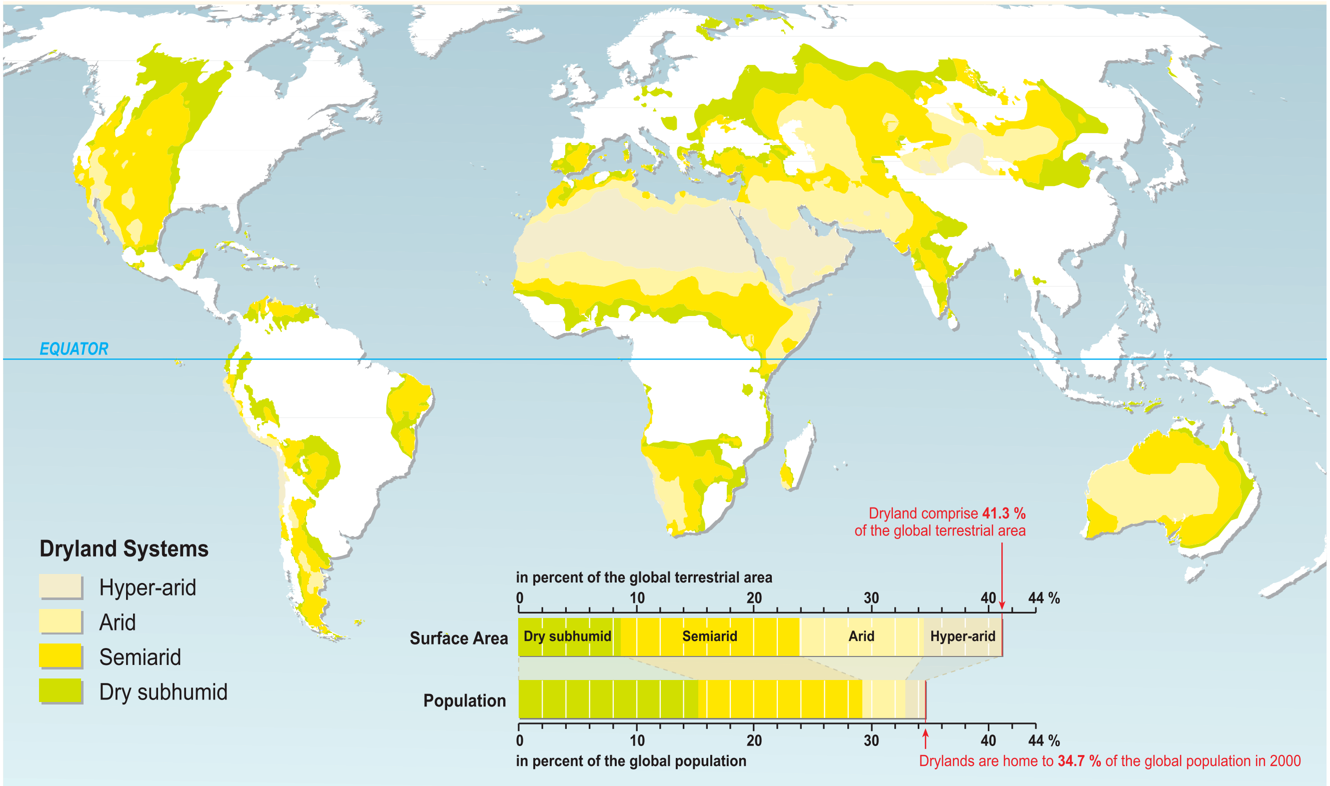
4.5.1 Recognizing desertification, land degradation and drought imperatives

Desertification, land degradation and drought (DLDD) constitute a ubiquitous challenge in the dryland regions of the world (Figure 4.7; Box 4.8), but are occurring in all agro-ecological zones and are increasingly considered a global problem with their extent and impacts affecting environmental and social vulnerability. Throughout the world DLDD affects arable lands, turning them into desolate wastes, affecting human livelihoods and well-being, exacerbating poverty and forced human migration, as well as inflicting destitution on the populations of vast areas and threatening them with food scarcity, malnutrition and famine.

Globally, DLDD affects 1.5 billion people who depend on degrading areas, and it is closely associated with poverty, with 42% of the very poor living in degraded areas, compared with 32% of the moderately poor and 15% of the non-poor (Nachtergaele et al. 2010). According to estimates, 24 billion tons of fertile soils are disappearing annually, and over the past 20 years the surface area lost is equal to all of the farmland of the USA. In the face of DLDD, it is estimated that a substantial proportion of the earth's natural forests have already been destroyed, and over 60% of ecosystem services are already degraded. This negative trend is set to continue at an accelerating pace over the next half century. For example, up to 90% of West Africa's coastal rain forests have disappeared since 1900 (MA, 2005*b*).

FIGURE 4.7

The extent of dryland systems worldwide (2000)



Notes: Drylands include all terrestrial regions where the production of crops, forage, wood and other ecosystem services are limited by water. Formally, the definition encompasses all lands where the climate is classified as dry subhumid, semiarid, arid or hyper arid. This classification is based on Aridity Index (AI) values. The AI is the long-term mean of the ratio of an area's mean annual precipitation to its mean annual potential evapotranspiration.
Source: MA (2005c, appendix A, p. 23, from data sources cited therein).

Those affected include the world's poorest, most marginalized and politically weak citizens. India alone accounts for 26% of this population, China 17% and sub-Saharan Africa 24%. The remaining part of the Asia-Pacific accounts for 18.3%. The other parts of the world are not far behind, with Latin America and the Caribbean accounting for 6.2% and North-East and North Africa 4.6% (ICRISAT, 2008). While DLDD affects all regions of the world, it has its greatest impact in Africa where two-thirds of the continent is desert or drylands.

Given desertification and land degradation, a number of countries in the drylands face increasing water scarcity. Most drylands have hyper-arid, arid, semi-arid and subhumid climatic conditions with limited water resources, which almost entirely depend on rainfall for replenishment. Rainfall is highly variable with considerable regional variations. Two, three or more consecutive dry years are experienced during some severe drought periods. Consequently, many people in the drylands suffer from a lack of access to water where it is very unevenly distributed.

BOX 4.8

Key facts on desertification

- Desertification occurs through land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities.
- Desertification is not, as commonly thought, the actual expansion of existing deserts.
- Desertification affects nearly 1 billion people, or one-sixth of the world's population.
- Desertification is occurring in 70% of all drylands, or one-quarter of the total land area of the earth.
- Desertification is responsible for the degradation of 73% of the world's rangeland.
- Desertification is especially severe in Africa, where two-thirds of the continent is desert or drylands, and where 73% of its agricultural drylands are already seriously or moderately degraded.
- Asia contains the largest amount of land affected by desertification of any continent-just under 1400 million ha.
- Nearly two-thirds of Latin America's drylands are moderately to severely desertified.
- Desertification is estimated to cost the world more than US$40 billion a year in lost productivity.

Source: Reproduced from Rogers (1995).

Such is the case in sub-Saharan Africa, where 800 million people live, with a population growth rate of more than 2.5% (Carles, 2009). Statistical analysis of rainfall patterns in some of the drylands regions reveals a stepped drop in the early 1970s, which has persisted. An analysis of the situation indicates a reduction of approximately 20% in precipitation levels, which results in a 40% reduction in surface runoff (EU, 2007).

4.5.2 The impacts of DLDD on water resources

A variety of human activities modify the landscape, such as deforestation, veldt fires and inappropriate farming and animal husbandry practices. These result in the degradation and desertification of watersheds and catchment areas, and reduce the amount of usable safe water available downstream. Often, such landscape modifications tend to exacerbate soil erosion and reduce the soil water-holding capacity, and decrease the recharge of groundwater and existing surface water storage capacity, through siltation and sedimentation of rivers and reservoirs that subsequently result in water scarcity over time. Furthermore, the draining of wetlands reduces water availability to recharge groundwater, resulting in water scarcity in the long term as the groundwater table recedes. In addition, the diversion of rivers for agricultural (irrigation) or industrial purposes deprives rivers and lakes of their usual flow, contributing to water scarcity in their hinterland.

Desertification is a major culprit in inducing water scarcity through direct reduction of freshwater reserves. It directly impacts river flow rates by increasing river water turbidity, which in turn enhances siltation and sedimentation in surface water reservoirs and estuaries. Desertification also negatively impacts groundwater tables by reducing a soil's capacity to allow water to percolate in the event of rainfall. In the face of desertification and the resultant water scarcity, accelerated and often rampant exploitation of underground water reserves frequently occurs to meet socio-economic needs, leading to gradual depletion of groundwater and increased water scarcity.

Rich dryland nations like Australia are not immune to water scarcity either. Drought is causing acute water shortages in large parts of Australia, Africa, Asia and the USA (Morrison et al., 2009). Regardless, an urban Australian on the average consumes 300 L water daily and a European 200 L, while in sub-Saharan Africa an individual makes do with less than 20 L per day (Natarajan, 2007). Besides droughts, river flows

> "In the drylands, the timing of drought and the lack of suitable technological options often limit the flexibility of poor households to make tactical adjustments in drought management practices to reduce losses."

and water supplies are being reduced by shrinking snow caps across China, India and Pakistan – countries where more than 1 billion people already lack access to safe drinking water and adequate sanitation (Morrison et al., 2009).

Often absent in these affected areas are efficient and reliable early warning systems to alert the populations of impending DLDD-related disasters. In the drylands, the timing of drought and the lack of suitable technological options often limit the flexibility of poor households to make tactical adjustments in drought management practices to reduce losses (Pandey et al., 2007). Where rains are late, farmers mostly delay planting or replant when suitable opportunities arise, and may reduce fertilizer use. When droughts and water scarcity are late, the opportunities for crop management adjustments to reduce losses are often no longer available.

One of the major impacts of DLDD-associated water scarcity is felt through food insecurity and starvation among affected communities, particularly in developing countries in the drylands. DLDD-related water scarcity brings about uncertainties that inevitably make communities vulnerable. The major issue is the inevitable failure of agriculture, because it is the largest water-consuming sector of poor economies (Carles, 2009). Thus, if dryland countries could reduce the impacts of DLDD on water resources and achieve water security, opportunities of achieving food security would be greatly enhanced. It is therefore essential for countries to take appropriate measures to address DLDD imperatives in the quest for greater water and food security.

In response to DLDD, some governments and water authorities resort to investing in supply-side measures that increase the extraction of countries' water resources, such as river diversions, construction of water reservoirs and groundwater pumping. Other investments that can be made include water-efficient processes, water-saving irrigation schemes and water recycling and reuse. Some of these measures, while they enhance water availability and accessibility and improve the prospects for water security, bring environmental and further financial costs, reduce downstream water security and aggravate water stress.

The Aral Sea and Lake Chad, for example, are disappearing because of upstream infrastructure developments. Lake Chad has lost 95% of its size since the 1960s. River diversion can also cause conflicts where a basin is shared by a number of riparian countries. For example, a number of river basins in Africa are shared by more than five riparian states, including the Congo (13), the Niger (11), the Nile (10), the Zambezi (9) Lake Chad (8) and the Volta (6) (Carles, 2009). The monitoring and management of such transboundary water resources is more complex and can pose greater risks in terms of DLDD if improperly managed, particularly for downstream users.

4.5.3 Combating DLDD imperatives to mitigate the challenges of water scarcity

Desertification should not be considered as an isolated process and neither should its mitigation processes. It constitutes an integral part of socio-economic development involving sustainable management of the land and water resources. Thus, combating desertification is complex and difficult, and usually impossible without alteration of the very land management practices that led to its occurrence.

A variety of different measures are being applied worldwide to reduce land degradation and avert desertification and water scarcity. In rice paddies throughout the mountainous regions of Asia, terracing is employed to restrain water erosion. On less steeply sloping land, contour strip-farming works well. Conservation agriculture, which includes both no-till and minimum tillage, is an additional tool in soil conservation. Conservation agriculture is widely used in Argentina, Australia, Brazil, Canada and the USA, as well as in some parts of Africa, Asia and Europe, (Brown, 2006).

The promotion of soil, water and vegetation conservation, combined with measures to rehabilitate, conserve and protect the natural environment, are prerequisites for sustainable land management (SLM). Practising SLM is one of the few options for sustaining livelihoods and generating income without destroying the quality of the land and the water resources, which are needed for agricultural production, food security, protection of biological diversity, as well as preventing and mitigating DLDD imperatives.

Decisions on how best to combat DLDD must also be based on solid scientific and economic analysis, recognizing the importance of local knowledge in cross-sectoral land and water resources management, and shifting focus from human uses of freshwater as a technical issue to the role of freshwater in catchments for the generation of ecosystem and societal services. Any policies adopted should enable participation of key stakeholder and incorporation of their ecological knowledge into institutional structures in a multi-level governance system. Consequently, the development of solutions must necessarily be inclusive and multi-sectoral (Climate Institute, 2009).

Finally, successful policies recognize that freshwater systems are complex and adaptive and can be degraded irreversibly (SIWI, 2009). The effects of DLDD can be felt globally, but the solutions are most often of a local, national or regional nature. An integrated and coordinated approach to combat DLDD, at local, national and transboundary levels, and policies that are highly integrated, are required to mitigate the various problems associated with water scarcity.

4.6 In or out of balance?

4.6.1 Balancing uses and supplies: Notions of water stress and water scarcity

As described throughout Chapter 2, the global demand for water is expected to grow significantly for all major sectors using water.

Although predicting future water demands for agriculture – the greatest user of water by far – is fraught with uncertainty, global agricultural water consumption is estimated to increase by about 20% by 2050. This increase could be even higher if substantial improvement in productivity of rainfed and irrigated agriculture are not set in place to meet the increasing demand for food from population growth and changing diets.

The growing demand for energy will also create increasing pressure on water resources, especially in sub-Saharan Africa and in the least developed countries of South Asia, which account for 80% of the 1.5 billion people lacking access to electricity globally. Growing demand for biofuels and other water-intensive energy sources, such as bituminous sands and shale gas, will only add to the energy sector's growing water footprint.

Proportionally, water use by the industry sector tends to increase with rising levels of national development, as growing economies shift from agriculture-based to more diversified economies. Demand should therefore be expected to see the highest rate of growth in countries with the fastest growing economies.

Like energy and industry, demand for water supply and sanitation services will also increase particularly in developing countries. Although the MDGs have helped to elevate the importance of these services onto national and international policy agendas, much remains to be done. Furthermore, national and local governments, which are ultimately responsible for meeting the growth in domestic demand, will still need to compete with other sectors for often-limited water supplies.

Ecosystems are both users (Chapter 2) and suppliers (Section 4.2) of water. Some water is required for the protection and maintenance of healthy ecosystems, which in turn provide important services related to water quality and protection against extreme events, as well as maintaining livelihoods among other benefits.

Human health (Section 4.1) will also vitally benefit from healthy ecosystems, safe water resources, and water supply and sanitation services. Maintaining human health through water translates into productivity gains from income earned from those saved from premature death from diarrhoea, gains in health care services in treating fewer patients, and the direct costs to patients of medication and transportation, as well as the time-saving benefits for people currently with inadequate services who gain access to nearby water and sanitation facilities.

As described in the previous section of this chapter, the increasing number and cost of water-related disasters create negative consequences that directly affect human livelihoods and impact national development.

While per capita consumption of water is decreasing in most of the industrialized world, overall demand for water is increasing throughout all major use sectors, driven primarily by the growing demands for food and energy in the developing world and emerging economies. This will invariably increase pressure on the earth's limited water resources, which in many regions are already experiencing varying levels of water stress. The world is transitioning to a new era where finite water constraints are starting to limit future economic growth and development, and it is becoming clear that even renewable water resources cannot supply enough water if not managed carefully (Patterson, 2009).

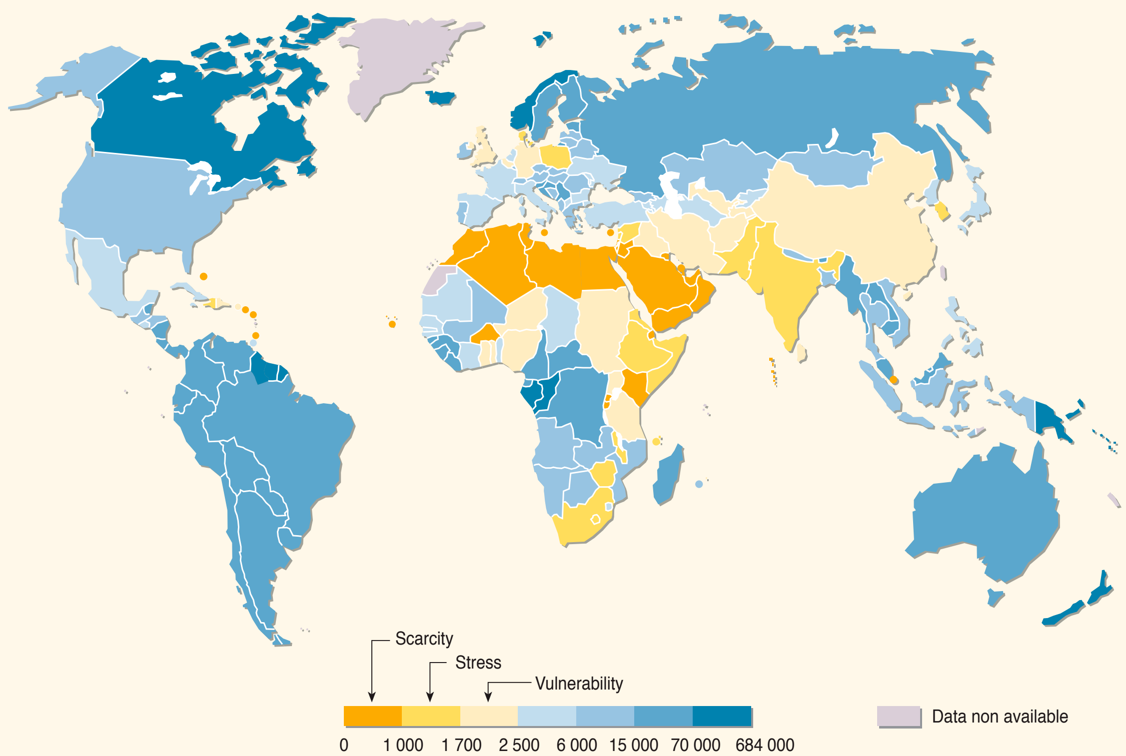
Water stress and water scarcity

'Hydrologists typically assess scarcity by looking at the population-water equation. An area is experiencing water stress when annual water supplies drop below 1,700 m^3 per person. When annual water supplies drop below 1,000 m^3 per person, the population faces water scarcity, and below 500 m^3 "absolute scarcity"' (UN-Water, n.d.) (Figure 4.8).

The notions of water stress and water scarcity might appear synonymous, but this is not always the case, and different definitions have been used to describe these terms, sometimes leading to confusion. For example, the term *water stress* is generally used to describe the ratio of water use (i.e. the amount of water withdrawn from the natural hydrological system) over the total amount of renewable water available. Thus, the higher the use as a fraction of available water, the higher the stress on the supply system.

FIGURE 4.8

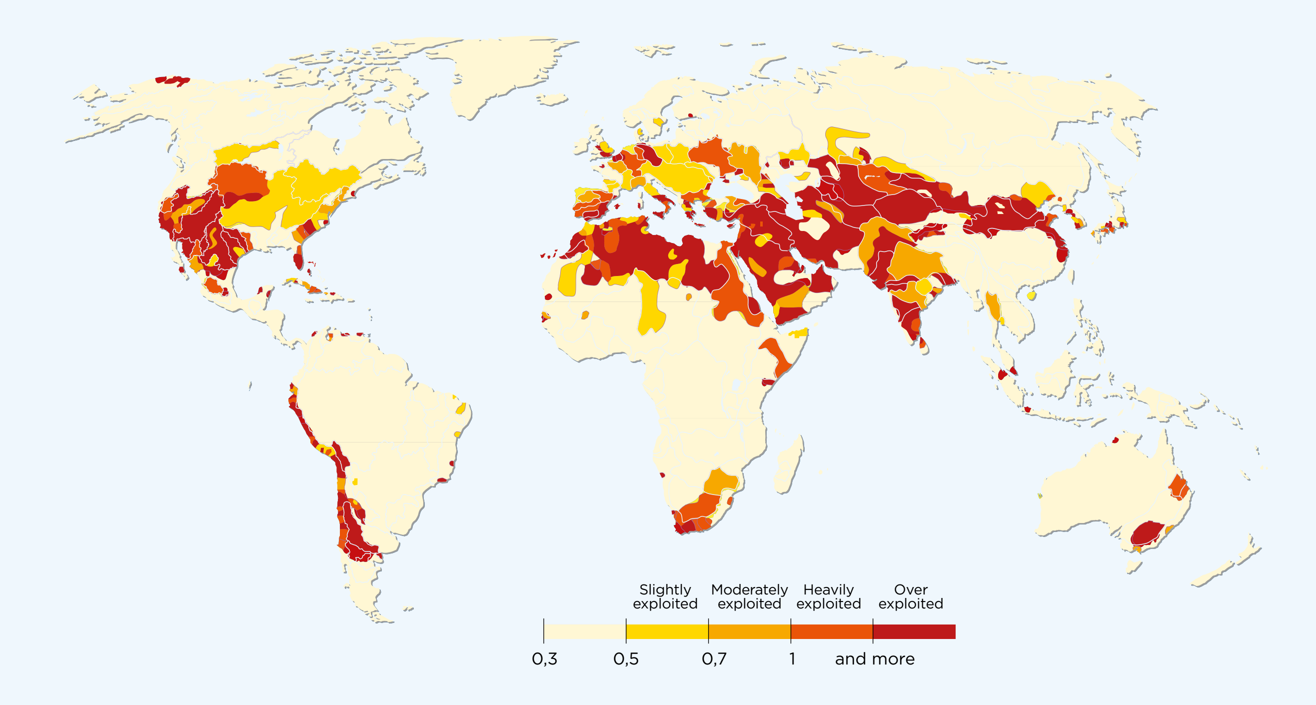
Freshwater availability (m^3 per person per year, 2007)



Source: UNEP/GRID-Arendal (2008) (http://maps.grida.no/go/graphic/global-waterstress-and-scarcity, P. Rekacewicz [cartographer] (Le Monde diplomatique), with sources FAO and WRI).

FIGURE 4.9

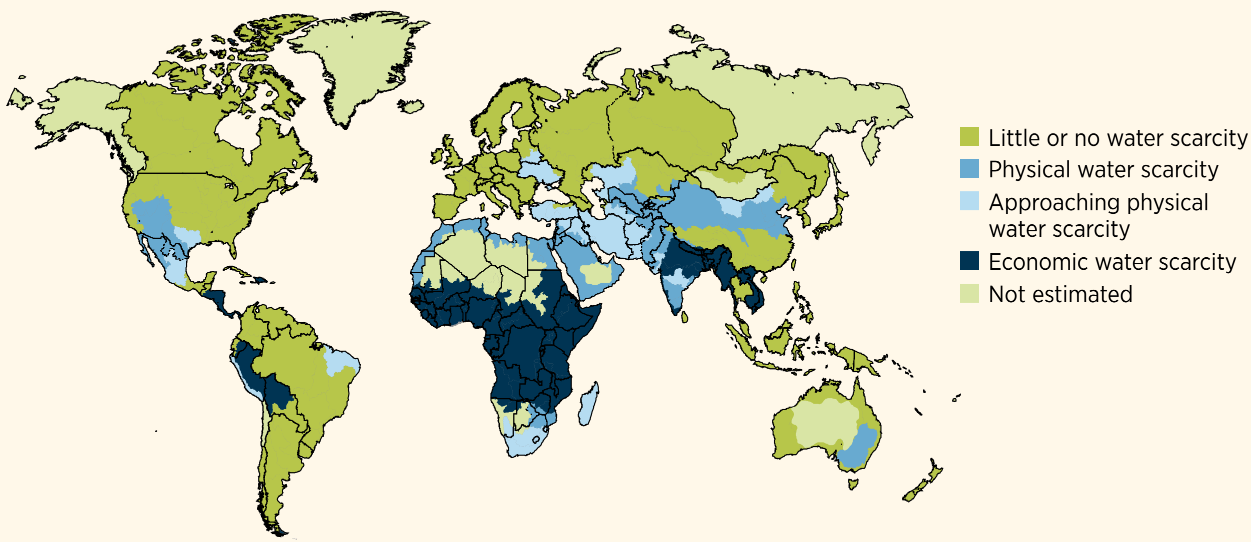
Global Water Stress Indicator (WSI) in major basins



Source: UNEP/GRID-Arendal (2008) (http://maps.grida.no/go/graphic/water-scarcity-index, P. Rekacewicz [cartographer], with sources Smakhtin, Revenga and Döll [2004]).

FIGURE 4.10

Global physical and economic water scarcity



Definitions and indicators

- Little or no water scarcity. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- Physical water scarcity (water resources development is approaching or has exceeded sustainable limits). More than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.
- Approaching physical water scarcity. More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Source: Comprehensive Assessment of Water Management in Agriculture (2007, map 2.1, p. 63, © IWMI, http://www.iwmi.cgiar.org/).

Several researchers and agencies have computed the *water stress* of watershed and grid scales by incorporating domestic, industrial and agricultural water consumption, against renewable supplies of water from precipitation, rivers and groundwater. Figure 4.9 shows one such map, which is consistent with other maps (e.g. Maplecroft, 2011; Smakhtin et al, 2003; Veolia Water, 2011) as each is based on similar – if not identical – datasets. The Arab Region countries nations have the highest levels of water stress, as well as major parts of Eastern China, India and the south-western USA.

However, under this definition, low water stress does not automatically imply ready access to water, which is a paradox that a large swath of the global population currently face. Whereas *water stress* is a function of the *availability* of water resources, the concept of *water scarcity* is also a function of *access*. In this regard, *economic scarcity* – whereby access is not limited by resource availability, but by human, institutional and financial constraints over distribution of the resource to different user groups – forms a major part of this paradox. Figure 4.10 illustrates global physical and economic water scarcity.

According to UN-Water,[2] water scarcity is defined as the point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully. Thus, where water 'stress' is a *physical* concept, water 'scarcity' is therefore a *relative* concept and can occur at any level of supply or demand. 'Scarcity may be a social construct (a product of affluence, expectations and customary behaviour) or the consequence of altered supply patterns – stemming from climate change for example' (UN-Water, n.d.).

The physical scarcity regions are consistent with the high-stress regions in Figure 4.9. However, regions such as central Africa, north-eastern India, north-eastern parts of South America and South-East Asia, which have medium to low water stress (Figure 4.9), experience water scarcity which is purely due to institutional and economic barriers.

Although finite, as described in Chapter 3, the world's freshwater resources can be highly variable over time and across rivers basins as a function of climate variability. Climate change will affect both precipitation patterns as well as the melting of snow and ice, resulting in increasing variability in the flows of surface waters from which most of our freshwater is withdrawn.

"Economic, social and political crises have been emerging at an accelerated rate. Although often described individually – the 'food' crisis, the 'energy' crisis, the 'financial' crisis, the 'human health' crisis, or the 'climate change' crisis, to name but a few – these crises are all inter-related though their causes and consequences. Their underlying causes often boil down to the ever-increasing competition for a few key – often-limited – resources, of which water is common to all."

Climate change models are constantly improving and generating new information, but additional research efforts are required to update our knowledge concerning possible future conditions, especially at regional and basin-level scales. Furthermore, several of the world's major aquifers, especially in arid and semi-arid regions, are being depleted due to intensive use of these limited and highly vulnerable reserves.

It is therefore highly unlikely that our increasing demand for water will be met solely through supply-oriented solutions. Rather, the key solutions to the global – and most regional and local – water crises resides in our ability to better manage demand while seeking to balance and maximize the various benefits of water.

4.6.2 Water as the nexus for sectors related to development and poverty reduction: Balancing the trade-offs

Food, energy, opportunity for economic growth, human and environmental health, and protection against water-related disasters are all necessary ingredients of development, including income generation and poverty reduction. They all depend on water. Yet these challenges have too often been dealt with in isolation rather than as part of an overarching and strategic framework across society and the economy. As a result, different developmental sectors often find themselves competition with each other for the finite water resources upon which they all depend. Therefore, in countries and regions where water resources are limited, decisions made to generate benefits from one sector often produce negative consequences for other sectors, through water, such that the overall economic and developmental gains from one sector are offset by losses to another.

This situation can ultimately lead to short-term and unsustainable decision-making and increase the number of people affected by water shortages. Climate change exacerbates this problem still further (Steer, 2010). Modern economic thinking and policy-making have created an economy that is so out of alignment with the ecosystem on which it depends that it is approaching collapse (Brown, 2011). Changing this situation will require the full inclusion of considerations for water within the existing governance frameworks under which water is managed – across sectors and regions, locally and globally – through representative institutions that have the appropriate authority. Water managers, in turn, need to be familiar with tools to measure social and economic impacts of their interventions. It is important that they have an understanding of the social context and existing power relations before introducing a new project and informing decision-makers accordingly. This approach will assist in selecting solutions best suited to the community, which will be sustainable in the long term.

Economic, social and political crises have been emerging at an accelerated rate. Although often described individually – the 'food' crisis, the 'energy' crisis, the 'financial' crisis, the 'human health' crisis, or the 'climate change' crisis, to name but a few – these crises are all inter-related though their causes and consequences. Their underlying causes often boil down to the ever-increasing competition for a few key – often-limited – resources, of which water is common to all. These inter-related crises also have consequences that negatively affect growth and development prospects and have disproportionate, negative effects on the poor and vulnerable.

Various approaches to international governance, as elaborated in Chapter 1 – whether the MDGs or such policy tracks for sustainable development as Rio+20 and the 'green economy'[3] – have failed to recognize the central role of water as a key ingredient of poverty reduction and sustainable development, cutting across the spectrum. In both cases, water is recognized as another 'sector', to be addressed more or less independently of the other sectors. This may seem appropriate from a purely 'drinking water and sanitation services' perspective, as is the case for the MDG target on drinking water and sanitation. It may also seem appropriate when calling for the investment in infrastructure, water-policy reform and in the development of new technology required to bridge the gap between global supply and water withdrawals (UNEP, 2011) as a specific sector of the green economy. However, such an approach across the board further compartmentalizes water in terms of national policies as different ministries and other authorities become responsible for their own commitments in terms of health, food and agriculture, energy or urban settlements. In fact, it is these policy decisions that ultimately determine how water resources are to be allocated. Therefore, the 'water-policy reform' (for example, as called for under the green economy in the statement above) would actually entail a broader reform of national policies whereby considerations for water are fully included in decisions regarding each political sector. And this is where water managers can inform the process.

A similar argument applies to the various global crises outlined above, for which proposed solutions are often compartmentalized and give little or no consideration to the central importance of water.

Over the past few years, the term 'nexus' has been used to describe the point at which different social, economic and/or environmental sectors are linked to each other. Climate change and energy are a perfect example; in this case the nexus is greenhouse gas. In agriculture, increased competition over land and water between crops grown for food and those grown for biofuels lead to the 'food-energy nexus'. Recognizing the important role of water, managing the water-food-energy-climate nexus has been the subject of analysis and discussion. Ecosystems, human health and urbanization/migration, with their links to competition over water, meet the others at the same nexus.

Although it may seem logical to accept that different sectors can be 'in competition' over water, it is clear that all the benefits of water are required for sustainable economic development. Where water resources are limited, certain trade-offs are required to allocate water towards different uses in order to maximize the overall return made up by the benefits water provides though different developmental sectors. This is a critical yet difficult and complex challenge. Chapter 10 focuses on this challenge, making the case that decisions about water allocation are not merely social or ethical, but are also economic, such that investing in water infrastructure and management generates increasing returns though these various benefits.

Notes

1 See Section 3.1 for a discussion of the teleconnections among different drivers of the global water cycle.

2 See the UN-Water website on the International Decade for Action 'Water for Life, 2000–2015' at http://www.un.org/waterforlifedecade/scarcity.shtml

3 According to UNEP (2011), the 11 key sectors of the 'green economy' are agriculture, buildings, cities, energy, fisheries, forestry, manufacturing, tourism, transport, waste management and water.

References

Adikari, Y. and Yoshitani, J. 2009. *Global Trends in Water-Related Disasters: an Insight for Policymakers. UN World Water Assessment Programme.* Insights. Paris, UNESCO.

Adjami, A. G., Toe, L., Bissan, Y., Bugri, S., Yaméogo, L., Kone, M., Katholi, C. R. and Unnasch, T. R. 2004. The current status of onchocerciasis in the forest/savanna transition zone of Côte d'Ivoire. *Parasitology*, Vol. 128, No. 4, pp. 407–14.

Ali, M., Emch, M., Donnay, J. P., Yunus, M. and Sack, R. B. 2002. Identifying environmental risk factors for endemic cholera: a raster GIS approach. *Health & Place,* Vol. 8, pp. 201–10.

Anderson, D. A., Gilbert, P. M. and Burkholder, J. M. 2002. Harmful algal blooms and eutrophication: Nutrient sources, composition, and consequences. *Estuaries,* Vol. 25, No. 4b, pp. 704–26.

Andrews, J. R. and Basu, S. 2011. Transmission dynamics and control of cholera in Haiti: An epidemic model. *The Lancet,* Vol. 377, No. 9773, pp. 1248–1255.

Ausseil, A., Gerbeaux, P., Chadderton, W. L., Stephens, T., Brown, D. and Leathwick, J. R. 2008. *Wetland Ecosystems of National Importance for Biodiversity: Criteria, Methods and Candidate List of Nationally Important Inland Wetlands.* Contract report LC0708/158. Lincoln, New Zealand, Landcare Research New Zealand Limited/Department of Conservation.

Bai, Z. G., Dent, D. L., Olsson, L. and Schaepman, M. E. 2008. Proxy global assessment of land degradation. *Soil Use and Management,* Vol. 24, No. 3, pp. 223–34.

Barrett, R., Kuzawa, C. W., McDade, T. and Armelagos, G. J. 1998. Emerging and re-emerging infectious diseases: The third epidemiologic transition. *Annual Review of Anthropology,* Vol. 27, pp. 247–271.

Bates, B. C., Kundzewicz, Z. W., Wu, S. and Palutikof, J. P. (eds). 2008. *Climate Change and Water.* Technical Paper of the Intergovernmental Panel on Climate Change (IPCC). Geneva, IPCC.

Bouma, M. J. and Pascual, M. 2001. Seasonal and interannual cycles of endemic cholera in Bengal 1891-1940 in relation to climate and geography. *Hydrobiologia,* Vol. 460, pp. 147–56.

Bouwer, L. M. 2011. Have disaster losses increased due to anthropogenic climate change? *American Meteorological Society*, Vol. 92, No. 6, pp. 39–46.

Bradley, D. J. and Bos, R. 2010. Water storage: Health risks at different scales. J. Lundqvist. (ed.) *On the Water Front: Selecting from the 2009 World Water Week in Stockholm.* Stockholm, Stockholm International Water Institute (SIWI).

Brandling-Bennett, D., Libel, M. and Migliónico, A. 1994. *El cólera en las Américas en 1991.* Notas de población, No. 60, LC/DEM/G.149. Santiago, Latin American and Caribbean Demographic Center (CELADE).

Brown, C. and Lall, U. 2006. Water and economic development: The role of interannual variability and a framework for resilience. *Natural Resources Forum,* Vol. 30, No 4, pp. 306–317.

Brown, L. R. 2006. *Restoring the Earth: Rescuing a Planet under Stress and a Civilization in Trouble.* New York, W.W. Norton & Company.

––––. 2011. *World on the Edge: How to Prevent Environmental and Economic Collapse.* Washington DC, Earth Policy Institute.

Butchart, S. H. M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J. P. W., Almond, R. E. A., Baillie, J. E. M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K. E., Carr, G. M., Chanson, J., Chenery, A. M., Csirke, J., Davidson, N. C., Dentener, F., Foster, M., Galli, A., Galloway, J. N., Genovesi, P., Gregory, R. D., Hockings, M., Kapos, V., Lamarque, J. F., Leverington, F., Loh, J., McGeoch, M. A., McRae, L., Minasyan, A., Morcillo, M. H., Oldfield, T. E. E., Pauly, D., Quader, S., Revenga, C., Sauer, J. R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S. N., Symes, A., Tierney, M., Tyrrell, T. D., Vie, J. C. and Watson, R. 2010. Global biodiversity: Indicators of recent declines. *Science,* Vol. 328, pp. 1164–1168.

Carles, A. 2009. *Water Resources in Sub-Saharan Africa.* Peace with Water, 12–13 February 2009, European Parliament, Brussels. http://www.theworldpolitical forum.net/wp-content/uploads/wpf2009/02_peace_with_water_brussels/ doc/report_ africa_eng.pdf

CBD (Secretariat of the Convention on Biological Diversity). 2010*a*. *Global Biodiversity Outlook 3.* Montreal, Canada, CBD. http://gbo3.cbd.int/

––––. 2010*b*. *In-Depth Review of the Programme of Work on the Biological Diversity of Inland Water Ecosystems.* Paper presented at the 14th meeting of the Subsidiary Body on Scientific, Technical and Technological Advice, Nairobi, 10–21 May 2010. http://www.cbd.int/doc/meetings/sbstta/sbstta-14/official/sbstta-14-03-en.doc

Chapagain, A. K. and Orr, S. 2008. *UK Water Footprint: The Impact of the UK's Food and Fibre Consumption on Global Water Resources. Volume 1.* Godalming, UK, World Wide Fund for Nature (WWF).

Climate Institute. 2009. Website. Washington DC, Climate Institute. http://www.climate.org/topics/water.html

Colwell, R. R. 1996. Global climate and infectious disease: The cholera paradigm. *Science,* Vol. 274, pp. 2025–31.

Comprehensive Assessment of Water Management in Agriculture. 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture.* London/Colombo, Earthscan/International Water Management Institute (IWMI).

Constantin de Magny, G., Guégan, J. F., Petit, M. and B. Cazelles, B. 2007. Regional-scale climate-variability synchrony of cholera epidemics in West Africa. *BMC Infec. Dis.,* Vol. 7, No. 20.

Cyranoski, D. 2009. Putting China's wetlands on the map. Nature, Vol. 458, p. 134. Dimitríjevics, A. 2007. *Mainstreaming Gender into Disaster Recovery and Reconstruction.* Washington DC, The World Bank.

Drechsel, P., Scott, C. A., Raschid-Sally, L., Redwood, M. and Bahri, A. (eds). 2010. *Wastewater Irrigation and Health.* London, Earthscan.

EC (European Commission). 2007. *Water Scarcity and Droughts.* Second Interim Report, June 2007. Brussels, EC. http://ec.europa.eu/environment/water/quantity/pdf/comm_droughts/2nd_int_report.pdf

Erlanger, T. E., Keiser, J., Caldas De Castro, M., Bos, R., Singer, B. H., Tanner, M. and Utzinger, J. 2005. Effect of water resource development and management on lymphatic filariasis, and estimates of populations at risk. *American Journal of Tropical Medicine and Hygiene* Vol. 73, No. 3, pp. 523–33.

FAO (Food and Agriculture Organization of the United Nations). 2008. *Sustainable Land Management.* Rome, FAO. http://www.un.org/esa/sustdev/csd/csd16/ documents/fao_factsheet/land.pdf

GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit). 2007. *Mozambique: Early Warning System Protects Effectively Against Natural Disasters.* Eschborn, Germany, GIZ.

Granéli, E. and Turner, J. T. (eds) 2006. *Ecology of Harmful Algae.* Ecological Studies 189. Berlin/Heidelberg, Germany, Springer-Verlag.

Hellmuth, M. E., Mason, S. J., van Aalst, M. K., Vaughan, C. and Choularton, R. (eds). 2011. *A Better Climate for Disaster Risk Management.* Climate and Society No. 3. New York, Columbia University, International Research Institute for Climate and Society (IRI).

Hellmuth M. E., Osgood, D. E., Hess, U., Moorhead, A. and Bhojwani, H. 2009. *Index Insurance and Climate Risk: Prospects for Development and Disaster Management.* Climate and Society No. 2. New York, Columbia University, International Research Institute for Climate and Society (IRI).

Huq, A., Xu, B., Chowdhury, A. R., Islam, M.S., Montilla, R. and Colwell, R. R. 1996. A simple filtration method to remove plankton-associated *Vibrio Cholerae* in raw water supplies in developing countries. *Appl. Environ. Microbiol.,* Vol. 62, No. 7, pp. 2508–12.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 2008. *Climate Change and Desertification Put One Billion Poor People at Risk.* Hyderabad, India, ICRISAT. http://www.icrisat.org/Media/2007/media14.htm

IFRC (International Federation of Red Cross and Red Crescent Societies). 2009. *World Disasters Report 2009: Focus on Early Warning, Early Action.* Geneva, IFRC.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Fourth Assessment Report.* Geneva, IPCC.

Jiang, Z., Zengh, Q. S., Wang, X. F. and Hua, Z. H. 1997. Influence of livestock husbandry on schistosomiasis transmission in mountainous regions of Yunnan Province. *Southeast Asian Journal of Tropical Medicine and Public Health,,* Vol. 28, No. 2, pp. 291–5.

Keiser, J., Caldas de Castro, M., Maltese, M. F., Bos, R., Tanner, M., Singer, B. H. and Utzinger, J. 2005a. Effect of irrigation and large dams on the burden of malaria on a global and regional scale. *American Society of Tropical Medicine and Hygiene,* Vol. 72, No. 4, pp. 392–406.

Keiser, J., Maltese, M. F., Erlanger, T. E., Bos, R., Tanner, M., Singer, B. H. and Utzinger, J. 2005b. Effect of irrigated rice agriculture on Japanese encephalitis, including challenges and opportunities for integrated vector management. *Acta Tropica,* Vol. 95, No. 1, pp. 40–57.

Koelle, K., Rodo, X., Pascual, M., Yunus, M. and Mostafa, G. 2005. Refractory periods and climate forcing in cholera dynamics. *Nature,* Vol. 436, pp. 696–700.

Kroeger, A., Lenhart, A., Ochoa, M., Villegas, E., Levy, M., Alexander, N. and McCall, P. J. 2006. Effective control of dengue vectors with curtains and water container covers treated with insecticide in Mexico and Venezuela: Cluster randomised trials. *BMJ,* Vol. 332, pp. 1247–52.

Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S. and Schellnhube, H. J. 2008. Tipping elements in the Earth's climate system. *PNAS,* Vol. 105, No. 6, pp. 1786–93.

Lewis S. L., Brando, P. M., Phillips, O. L., van der Heijden, G. M. F. and Nepstad, D. 2011. The 2010 Amazon Drought. *Science,* Vol. 331, p. 554.

Lipp, E. K., Huq, A. and Colwell, R. R. 2002. Effects of global climate on infectious disease: The cholera model. *Clin. Microbiol. Rev.,* doi:10.1128/CMR.15.4.757-770.2002

Maplecroft. 2011. *Maplecroft Global Water Stress Index.* Bath, UK, Maplecroft. http://maplecroft.com/about/news/water_stress_index.html

Mariappan, T. 2008. *A Comprehensive Plan for Controlling Dengue Vectors in Jeddah, Kingdom of Saudi Arabia.* Pondicherry, India, Vector Control Research Centre.

Mariappan, T., Srinivasan, R. and Jambulingam, P. 2008 Defective rainwater harvesting structure and dengue vector productivity compared with peridomestic habitats in a coastal town in Southern India. *J. Med. Entomol.,* Vol. 45, 148–56.

Martin, S. F., Fagen, P. W., Poole, A. and Karim, S. 2006. *Philanthropic Grant-making for Disaster Management: Trend Analysis and Recommended Improvements.* Washington DC, Georgetown University, Institute for the Study of International Migration.

MA (Millennium Ecosystem Assessment). 2005a. *Ecosystems and Human Well-being: Wetlands And Water Synthesis.* World Resources Institute (WRI), Washington DC.

MA (Millennium Ecosystem Assessment). 2005b. *Living Beyond Our Means. Natural Assets and Human Well-Being: Synthesis from the Board.* World Resources Institute (WRI), Washington DC. http://www.millenniumassessment.org/documents/document.429.aspx.pdf

MA (Millennium Ecosystem Assessment. 2005c. *Ecosystems and Human Well-Being: Desertification Synthesis.* World Ressources Institute (WRI), Washington DC.

Molden, D. 2009. Planetary boundaries: The devil is in the detail. *Nature Reports Climate Change,* 910: 116. http://www.nature.com/climate/2009/0910/full/climate.2009.97.html

Molyneux, D. H., Ostfeld, R. S., Bernstein, A. and Chivian, E. 2008. Ecosystem disturbance, biodiversity loss, and human infectious disease. E. Chivian and A. Bernstein (eds) *Sustaining Life: How Human Health Depends on Biodiversity.* Oxford/New York, Oxford University Press, pp. 287–323.

Morrison, J., Morikawa, M., Murphy, M. and Schulte, P. 2009. *Water Scarcity and Climate Change: Growing Risk for Businesses and Investors.* Baston, MA, Ceres. http://www.pacinst.org/reports/business_water_climate/full_report.pdf

Myers, S. S. and Patz, J. A. 2009. Emerging threats to human health from global environmental change. *Annual Review of Environment and Resources,* Vol. 34, No. 1, pp. 223–52.

Nachtergaele, F., Petri, M., Biancalani, R., Van Lynden, G. and Van Velthuizen, H. 2010. *Global Land Degradation Information System (GLADIS): Beta Version. An Information Database for Land Degradation Assessment at Global Level.* Land Degradation Assessment in Drylands Technical Report No. 17. Rome, FAO.

Natarajan, G. 2007. Water scarcity is a real threat. *Financial Express.* Dehli, Indian Express. http://www.financialexpress.com/news/water-scarcity-is-a-real-threat/205820/

Neumayer, E. and Plümper, T. 2007. The gendered nature of natural disasters: The impact of catastrophic events on the gender gap in life expectancy, 1981-2002. *Annals of the Association of American Geographers*, Vol. 97, No. 3, pp. 551–66.

Nkem J., Oswald, D., Kudejira, D. and Kanninen, M. 2009. *Counting on Forests and Accounting for Forest Contributions in National Climate Change Actions.* Working Paper 47. Bogor, Indonesia, Center for International Forestry Research (CIFOR).

Nguyen, L. A. P., Clements, A. C. A., Jeffrey, J. A. L., Yen, N. T., Nam, V. S., Vaughan, G. V., Shinkfield, R., Kutcher, S. C., Gatton, M. L., Kay, B. H. and Ryan, P. A. 2011. Abundance and prevalence of *Aedes Aegypti* immatures and relationships with household water storage in rural areas of Southern Viet Nam. *International Health,* Vol. 3, No. 2, pp. 115–25.

Nygård, K., Andersson, Y., Røttingen, J. A., Svensson, Å., Lindbäck, J., Kistemann, T. and Giesecke, J. 2004. Association between environmental risk factors and campylobacter infections in Sweden. *Epidemiology and Infection,* Vol. 132, pp. 317–25.

Oxfam International. 2005. *The Tsunami's Impact on Women.* Briefing Note. Oxford, UK, Oxfam. http://www.oxfam.org.uk/what_we_do/issues/conflict_disasters/downloads/bn_tsunami_women.pdf

––––. 2007. *Climate Alarm – Disasters Increase as Climate Change Bites.* Briefing Paper. Oxford, UK, Oxfam. http://www.oxfam.org.uk/resources/policy/climate_change/downloads/bp108_weather_alert.pdf

PAHO (Pan American Health Organization). 2000. *Natural Disasters: Protecting the Public's Health.* Scientific Publication No. 575. Washington DC, PAHO.

Pandey, S. Bhandari, H. and Hardy, B. (eds) 2007. *Economic Costs of Drought and Rice Farmers' Coping Mechanisms.* International Rice Research Institute. http://www.philjol.info/index.php/IRRN/article/ viewFile/1078/971

Pascual, M., Rodo, X., Ellner, S. P., Colwell, R. and Bourna, M. J. 2000. Cholera dynamics and El Nino-Southern Oscillation. *Science,* Vol. 289, pp. 1766–9.

Patterson, K. A. 2009. Case for integrating groundwater and surface water management. D. Michel and A. Pandya (eds) *Climate Change, Hydropolitics, and Transboundary Resources.* Washington DC, Henry L. Stimson Center, pp. 63–72.

Piehler, M. F. 2008. Watershed management strategies to prevent and control cyanobacterial harmful algal blooms. H. K. Hudnell (ed.) *Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs.* (Advances in Experimental Medicine and Biology, Vol. 619). New York, Springer, pp. 259–73.

Prüss, A. and Mariotti, S. 2000. Preventing trachoma through environmental sanitation: a review of the evidence base. *Bulletin of the World Health Organization*, Vol. 78, pp. 258–266.

Rejmánková, E., Grieco, J., Achee, N., Masuoka, P., Pope, K. Robert, D. and Higashi, R. M. 2006. Freshwater community interactions and malaria. S.K. Collinge and C. Ray (eds) *Disease Ecology: Community Structure and Pathogen Dynamics.* Oxford, Oxford University Press, pp. 90–105.

Rockström J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., De Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. and Foley, J.A. 2009*a*. A safe operating space for humanity. *Nature,* Vol. 461, pp. 472–5.

––––. 2009*b*. Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society,* Vol. 14, No. 2, p. 32.

Rodo, X., Pascual, M., Fuchs, G. and Faruque, A. S. 2002. Enso and cholera: a nonstationary link related to climate change? *Proc Natl Acad Sci USA,* Vol. 99, pp. 12901–6.

Rogers, A. (ed). 1995. *Taking Action: An Environmental Guide for You and Your Community.* Nairobi, UNEP and the United Nations Non-Governmental Liaison Service. http://www.nyo.unep.org/action/Text/TOC-t.htm

Seng, C. M., Setha, T., Nealon, J., Chantha, N., Socheat, D. and Nathan, M. B. 2008. The effect of long-lasting insecticidal water container covers on field populations of Aedes Aegypti (L.) Mosquitoes in Cambodia. *Journal of Vector Ecology,* Vol. 33, No. 2, pp. 333–41.

SIWI (Stockholm International Water Institute). 2009. *Resilience: Going from Conventional to Adaptive Freshwater Management for Human and Ecosystem Compatibility.* Swedish Water House Policy Brief No. 3. Stockholm, SIWI. http://www.siwi.org/ documents/Resources/Policy_Briefs/PB3_Resilience_2005.pdf

Smakhtin, V. U., Revenga, C., Döll, P. and Tharme, R. 2003. *Putting the Water Requirements of Freshwater Ecosystems into the Global Picture of Water Resource Assessment.* Washington DC, WRI (World Resources Institute). http://earthtrends.wri.org/features/view_feature.php?fid=38&theme=2

Speelmon, E. C., Checkley, W., Gilman, R. H., Patz, J., Calderon, M. and Manga, S. 2000. Cholera incidence and El Nino-related higher ambient temperature. *JAMA,* Vol. 283, pp. 3072–4.

Steer, A. 2010. *From the Pump Room to the Board Room: Water's Central Role in Climate Change Adaptation.* Washington DC, The World Bank. http://www.d4wcc.org.mx/images/documentos/Presentaciones/andrew_steer_keynote_presentation_water_event_december_2_final.pdf (Accessed 23 April 2011.)

TEEB (The Economics of Ecosystems and Biodiversity). 2009. Website. Geneva, United Nations Environment Programme (UNEP). http://www.teebweb.org (Accessed 26 January 2011.)

Thomson M. C., Doblas-Reyes, F. J., Mason, S. J., Hagedorn, R., Connor, S.J., Phindela, T., Morse, A. P. and Palmer, T. N. 2006. Malaria early warnings based on seasonal climate forecasts from multi-model ensembles. *Nature,* Vol. 439, pp. 576–9.

Trench, P., Rowley, J., Diarra, M., Sano, F. and Keita, B. 2007. *Beyond Any Drought. Root causes of chronic vulnerability in the Sahel.* Sahel Working Group. London, International Institute for Environment and Development.

UN (United Nations). 2011. *United Nations Secretary General Report to the 66th General Assembly on the Implementation of the International Strategy for Disaster Reduction.* New York, UN.

UNEP (United Nations Environment Programme). 2007. *Global Environment Outlook 4.* Nairobi, UNEP.

––––. 2008. *Africa: Atlas of Our Changing Environment.* Nairobi, UNEP. http://www.unep.org/dewa/Africa/AfricaAtlas

––––. 2011. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication.* Nairobi, UNEP. http://www.unep.org/greeneconomy (Accessed 6 May 2011.)

UNEP/GRID-Arendal. 2008. *Vital Water Graphics. An Overview of the State of the World's Fresh and Marine Waters* (2nd edn). Nairobi, UNEP. http://www.unep.org/dewa/vitalwater/article48.html

UNISDR (United Nations International Strategy for Disaster Reduction Secretariat). 2009. *Global Assessment Report on Disaster Risk Reduction – Risk and Poverty in a Changing Climate. Invest Today for a Safer Tomorrow.* New York, UNISDR. http://www.preventionweb.net/english/hyogo/gar/report/documents/GAR_Chapter_2_2009_eng.pdf

––––. 2011. *Global Assessment Report on Disaster Risk Reduction.* Geneva, UNISDR.

United Nations University (UNU). 2004. *Two Billion People Vulnerable to Floods by 2050: Number Expected to Double or More in Two Generations.* News Release. Tokyo, Japan, UNU.

UNOCHA (UN Office for the Coordination of Humanitarian Affairs). 2011. *Eastern Africa Drought Humanitarian Report.* UNOCHA. http://reliefweb.int/home

UN-Water (n.d.). International Decade for Action (UN-IDfA): Water for Life, 2005–2015. Website. Zaragoza, Spain, UN-Water/UN-IDfA. http://www.un.org/waterforlifedecade/scarcity.shtml

USAID (US Agency for International Development). 2011. *Haiti – Earthquake and Cholera.* Fact Sheet 3, Fiscal Year 2011, 15 April, 2011. Washington DC, USAID.

Van Dolah, F. M., Roelke, D. and Greene, R. M. 2001. Health and ecological impacts of harmful Aagal blooms: risk assessment needs. *Human and Ecological Risk Assessment,* Vol. 7, No. 5, pp. 1329–45.

Veolia Water. 2011. *Finding the Blue Path for a Sustainable Economy.* White paper. Veolia Water/International Food Policy Research Institute (IFPRI).

Vörösmarty C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Reidy Liermann, C. and Davies, P. M. 2010. Global threats to human water security and river biodiversity. *Nature*, Vol. 467, pp. 555–61.

Walsh, J. F., Molyneux, D. H. and Birley, M. H. 1993. Deforestation: Effects on vector-borne disease. *Parasitology,* Vol. 106, Suppl.: S55–75.

WHA (World Health Assembly). 2011*a*. *Cholera: Mechanism for Control and Prevention.* 64th World Health Assembly, WHA64.15 Agenda item 13.9, 24 May 2011. http://apps.who.int/gb/ebwha/pdf_files/WHA64/A64_R15-en.pdf

––––. 2011*b*. *Drinking-Water, Sanitation and Health.* 64th World Health Assembly, WHA64.24 Agenda item 13.15, 24 May 2011. http://apps.who.int/gb/ebwha/pdf_files/WHA64/A64_R24-en.pdf

WHO (World Health Organization). 2007. *Our Cities, Our Health, Our Future: Acting on Social Determinants for Health Equity in Urban Settings.* Report to the WHO Commission on Social Determinants of Health from the Knowledge Network on Urban Settings. Kobe City, Japan. Geneva, WHO.

––––. 2008. *The Global Burden of Disease: 2004 Update.* Geneva, WHO.

––––. 2010*a*. Cholera, 2009. *Weekly Epidemiological Record*, Vol. 85, No. 31, pp. 293–308. Geneva, WHO.

––––. 2010*b*. *Haiti: Cholera Response Update.* 13 December 2010. Geneva, WHO.

––––. 2011*a*. Cholera, 2010. *Weekly Epidemiological Record,* Vol. 86, No. 31, pp. 325–340. Geneva, WHO. http://www.who.int/wer/2011/wer8631.pdf

––––. 2011*b*. *Guidelines for Drinking-Water Quality* (4th edn). Geneva, WHO.

––––. 2011*c*. *Water Safety in Buildings.* Geneva, WHO.

WHO/DFID (UK Department for International Development). 2009. *Vision 2030: The Resilience of Water Supply and Sanitation in the Face of Climate Change.* Geneva/London, WHO/DFID.

WHO/IWA (International Water Association). 2009. *Water Safety Plan Manual: Step-by-Step Risk Management for Drinking-Water Suppliers.* Geneva/London, WHO/IWA.

WHO/UNICEF. 2009. *Water, Sanitation and Hygiene Standards for Schools in Low-Cost Settings.* Geneva/New York, WHO/UNICEF.

––––. 2011. *Post-2015 Monitoring of Water and Sanitation.* Report of a first WHO/UNICEF Consultation. (Berlin, 3–5 May 2011). Geneva/New York, WHO/UNICEF.

WHO/UN-Water. 2010. *GLAAS 2010: UN-Water Global Annual Assessment of Sanitation and Drinking-Water.* Geneva, WHO.

Wilson, M. D., Cheke, R. A., Flasse, S. P., Grist, S., Osei-Ateweneboana, M. Y., Tetteh-Kumah, A., Fiasorgbor, G. K., Jolliffe, F. R., Boakye, D. A., Hougard, J. M., Yameogo, L. and Post, R. J. 2002. Deforestation and the spatio-temporal distribution of savannah and forest members of the Simulium Damnosum Complex in Southern Ghana and South-Western Togo. *Transactions of the Royal Society of Tropical Medicine and Hygiene,* Vol. 96, No. 6, pp. 632–9.

World Bank. 2004. *Natural Disasters: Counting the Costs.* Washington DC, The World Bank.

––––. 2010*a*. *Assessment of the Risk of Amazon Dieback. Main Report.* Washington DC, The World Bank.

––––. 2010*b*. *Natural Hazards, UnNatural Disasters, The Economics of Effective Prevention.* Washington DC, The World Bank/International Bank for Reconstruction and Development (IBRD).

WWAP (World Water Assessment Programme). 2006. *World Water Development Report 2: Water: A Shared Responsibility. Paris/New York, UNESCO/Berghahn Books.*

WWAP (World Water Assessment Programme). 2009. *World Water Development Report 3: Water in A Changing World.* Paris/London, UNESCO/Earthscan.

WWF (World Wide Fund for Nature). 2010. *Living Planet Report 2010: Biodiversity, Biocapacity and Development.* Gland, Switzerland, WWF. http://wwf.panda.org/about_our_earth/all_publications/living_planet_report

Xu, H., Tang, X., Liu, J., Ding, H., Wu, J., Zhang, M., Yang, Q., Cai, L., Zhao, H. and Liu, Y. 2009. China's progress toward the significant reduction of the rate of biodiversity loss. *BioScience,* Vol. 59, No. 10, pp. 843–52.

Zhou, X. N., Yang, G. J., Yang, K., Wang, X. H., Hong, Q. B., Sun, L. P., Malone, J. B., Kristensen, T. K., Bergquist, N. R. and Utzinger, J. 2008. Potential impact of climate change on schistosomiasis transmission in China. *American Society of Tropical Medicine and Hygiene,* Vol. 78, No. 2, pp. 188–94.

CHAPTER 5

Water management, institutions and capacity development

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As described throughout the preceding chapters (1–4), water is central to all aspects of development, underpinning every social and economic sector. How humans manage water is therefore vital to the growth and prosperity of communities and societies. Yet the term 'water management' is often used (and misunderstood) with many meanings ascribed to it, even among experts within the water community. But what does the term *really* mean? Protecting and managing the natural resource? Providing water-related services? Meeting allocation and entitlement agreements and distributing (sometimes limited) supplies across a broad range of complex, interlinked uses with increasingly uncertain demands? The short answer is *all of the above – and more*.

Previous editions of the *World Water Development Report* (WWDR) included calls for *sustainable*, *improved* and of course *integrated* water resources management. And indeed these concepts, along with *adaptive* management, are scattered throughout this fourth edition too, in terms of challenges and opportunities facing water management in different regions (Chapter 7); valuing and allocating water resources and benefits (Chapter 10); transforming water management institutions to deal with change (Chapter 11); and responding to risk and uncertainty from a water management perspective (Chapter 13).

Building on the water management-related issues addressed in previous WWDRs, this chapter begins with a description of what water management actually is, including a brief examination of how approaches to water management in some regions have evolved over the past century and how they might continue to evolve to deal with increasing uncertainties and associated risks (a discussion which is continued in Chapter 11). The chapter also provides a descriptive overview of water-related institutions, which collectively set out the 'rules of the game' for water management, and outlines some of the challenges these institutions will face in an increasingly uncertain future. The chapter concludes with a section highlighting the importance of knowledge and capacity as a critical element of institutional effectiveness.

With the exception of Section 5.1, the material in this chapter has been condensed from the challenge area reports (Part 3/Volume 2) 'Water and institutional change: Responding to present and future uncertainty' (Chapter 25) and 'Developing knowledge and capacity' (Chapter 26).

5.1 Why do we need to manage water?

Water is a fugitive resource, flowing through space and time across landscapes and through economies. All benefit from it, but few understand how it is actually managed. The management of water is not merely a technical issue; it requires a mix of measures including changes in policies, prices and other incentives, as well as infrastructure and physical installations. Integrated water resources management (IWRM) focuses on the necessary integration of water management across sectors, policies and institutions.

Water management is underpinned by levels of *uncertainty*. These are changing as a consequence of global trends in demography, consumption patterns and migration, and climate change, resulting in increased levels of risk (see Chapters 8 and 9). Adapting to these uncertainties and developing strategies that mitigate against emerging risks makes water management policies, institutions and regulations more resilient, thereby increasing their chances of generating benefits to society. Adaptive water management extends to IWRM by focusing on a more flexible management process to address uncertainty and include actors whose decisions affect water, but who do not currently participate as an active part of the water management process.

5.1.1 Characteristics of water management systems

As water moves in time and space consistent with the hydrological cycle, the term 'water management' covers a variety of activities and disciplines. Broadly speaking, these can be divided into three categories: managing the resource, managing water services, and managing the trade-offs needed to balance supply and demand. Water *resource* management is about managing water found in rivers, lakes and groundwater. This includes water allocation, assessment and pollution control; the protection of water-related ecosystems and water quality; natural and man-made infrastructure for the redistribution and storage of these resources; and groundwater recharge. Water *service* management consists of managing reticulation systems from the bulk water supplier, through the processing phases, up to the point of need by the end user; and again capturing the waste streams for reticulation back to a wastewater treatment plant for safe onward discharge. The management of *trade-offs* concerns a range of administrative activities that meet allocation and entitlement agreements across a wide spectrum of socio-economic interests. Each activity has different requirements, but together they add up to what is called *water management*.

Water management is unique. It touches upon almost every aspect of human well-being with links to socio-economic development, safety, human health, the environment and even cultural and religious beliefs (Dalcanale et al., 2011). For example, all nations, developed as well as developing, are vulnerable to rare and extreme flood events. This was demonstrated in 2005 by the devastation wrought by hurricane Katrina in the southern United States of America, by the massive flooding which took place in Pakistan in 2010, and the inundations caused by tsunamis in various parts of southern and eastern Asia over the last decade. Less visible, but often no less disastrous, effects occur through droughts such as that being experienced in the Horn of Africa in 2011 (where loss of crops threaten the lives of thousands of people), or through slow onset disasters such as the shrinking of the Aral Sea, which has affected many livelihoods, the flow of toxic acid mine drainage from various mining areas of South Africa (Coetzee, 1995; Coetzee et al., 2006; Hobbs et al., 2008; Winde, 2009; Winde and van der Walt, 2004), and the lack of adequate water supply and sanitation, which causes a range of diseases and loss of lives in many parts of the world. Yet socio-economic development is dependent on, and therefore a function of, available water supplies. Thus, proper water management is of vital importance to human society in a world where increasing demands are being placed on a relatively finite but potentially renewable resource.

Water management over the twentieth century often involved large infrastructure projects such as dams and river diversions (WCD, 2000). This has often been described as the *Hard Path Approach* by certain authors (Wolff and Gleick, 2002), or the *Hydraulic Mission* phase of economic development by others (e.g. Allan, 2000). These projects were used to address both conditions of water scarcity and water excesses; namely, the construction of artificial water storage facilities (dams) or the exploitation of natural systems (aquifer storage and recharge), allowing water to be stored for use during periods of scarcity, and controlling its potentially devastating impacts during floods. The course of human development has not necessarily followed natural patterns of sustainability; rather, the sustainability of water resources has in many locations been overwhelmed by the continually expanding human activities associated with socio-economic development, including agricultural production, urbanization and industrialization. Many of these demands are naturally in conflict, raising the need to manage trade-offs. While

“The world is transitioning to a new era where finite water constraints are starting to limit future economic growth and development.”

all waters are under pressure globally, groundwater is of particular concern: increasing exploitation as a result of improved drilling and pumping technology has resulted in situations of severe depletion in many countries (see Chapter 3). The world is transitioning to a new era where finite water constraints are starting to limit future economic growth and development. It is becoming clear that even renewable water resources cannot supply enough water if not managed carefully (Patterson, 2009).

The twentieth century was characterized by the dam-building era, as engineering design improved and better steel-reinforced concrete became available. This gave rise to what can be termed the ‘infrastructure approach’, as an element of the *Hard Path Approach* or the *Hydraulic Mission*, in which it was believed that the mere provision of hard infrastructure would suffice to meet the varied needs of humanity (Allan, 2000). Over time the limitations of the hard infrastructure approach have become increasingly clear (Snaddon et al., 1999). For example, in the Netherlands, it was realized that continual heightening of dykes was ultimately unsustainable. This has led to a new approach that foregrounds respect for natural hydrological conditions and acknowledges the limitations to the benefit of hard infrastructure (van Stokkom et al., 2005). Experience is now showing that substantial alterations in hydrological conditions, most notably changes in the natural flood pulse (Junk et al., 1989; Puckridge et al., 1993) caused by interventions such as inter-basin transfers (Snaddon et al., 1999), have led to unintended consequences, sometimes called *revenge effects* (Tenner, 1996). These include the deterioration of ecosystems, especially wetlands, which if left unaltered offer a wide range of ‘benefits that are often essential to maintaining a basic standard of living in both urban and rural areas’ (Emerton and Bos, 2004, p. 20). Natural ecosystems such as forests and wetlands generate important economic services which maintain the quantity and quality of water supplies. Furthermore they help to mitigate or avert water-related disasters such as flooding and drought (Emerton and Bos, 2004).

Contemporary water managers have to deal with an increasingly complex picture. Their responsibilities entail managing variable and uncertain supplies to meet rapidly changing and uncertain demands; balancing ever-changing ecological, economic and social values; facing high risks and increasing unknowns; and sometimes needing to adapt to events and trends as they unfold. In short, the management of water increasingly focuses on risk and uncertainty, and the emerging range of drivers and impacts often lie outside the traditional water arena. Moreover, effective water management demands transboundary coordination in a context where a total of 276 international river basins cover almost half the earth’s surface (Bakker, 2007; De Stefano et al., 2010; OSU, n.d., 2008 data), and some 273 identified transboundary aquifers underpin various national economies (Puri and Aureli, 2009).

Water management consequently is not only a technical issue, but also one that requires a much more nuanced and holistic approach to achieve its goals. During the twentieth century the focus was traditionally on structural options for water management – developing physical infrastructure to ‘tame’ or ‘control’ water. Today, in the countries that have achieved essential water infrastructure development, there is a need for increased attention on non-structural management options to deal with the limitation of infrastructural interventions in hydrological systems, underpinned by growing uncertainty. Emerging twenty-first century water management can be thought of as increasingly focused on soft infrastructure, most notably associated with the management of trade-offs, and increasingly dependent on institutions, policy, legislation and dialogue between competing users (see Chapter 11). Some authors refer to this as the *Soft Path Approach* (Brooks et al., 2009; Wolff and Gleick, 2002). Having benefited from decades of infrastructure development, the challenge for most developed countries is to incorporate soft measures into existing water management frameworks. However, most developing countries are still in the process of meeting the most basic levels of water infrastructure development. The challenge for these countries will be to adopt and balance elements of both the hard and soft paths, in order to maximize the benefits (and minimize the costs and risks) of both approaches.

Water management through infrastructure development

The hard approach to water management typically focuses on the construction of water storage, transport, treatment, flood protection, and other regulation and delivery (distribution and collection) systems; hydropower plants; and groundwater wells and pumps, consistent with the goal of seeking additional water supplies. The capacities of these structures have typically been based on historical records of flows, stages and demands projected into the future or for some return period (frequency). Some countries are busy constructing such infrastructure to make use of their often-scarce water resources, such as for irrigation, domestic and industrial uses, and sometimes for environmental purposes. Other countries are devoting considerable attention to the protection of their growing populations from flooding, while others remove or modify some of their hard infrastructure, mostly to enhance environmental and ecosystem services and their associated benefits.

Hard infrastructural measures include the high costs of maintaining hydrological fixes for prolonged periods and the risk of degraded performance over time. These are still required by countries facing economic water scarcity (see Section 4.6), where the social and economic benefits of such measures can greatly out way the costs. Moreover, the costs of reducing the unexpected negative impacts of these measures may be high. Long-term planning is therefore critical, although fraught with uncertainties. Increasing emphasis on stakeholder participation is designed to balance trade-offs between impacts on ecological systems and potential benefits. While this is more democratic, it places greater demands on political leadership and governance structures, and can sometimes delay project implementation, so it is not without risk.

Although water demand management can substantially reduce water needs and will always remain a central component to sound management (see Chapter 11), there is still a substantial requirement for increased water storage, which necessarily increases with socio-economic development and climate change. Innovative storage infrastructure can sometimes help to overcome the disadvantages of hard infrastructural measures, while maintaining their advantages. The potential of working with nature by using 'green' infrastructure (such as wetlands) and less intrusive dams, therefore offers very promising opportunities (Wolff and Gleick, 2002). One example is the use of permeable surface coatings in urban areas, rather than concrete, to reduce storm water runoff while enhancing the urban ecosystem; however, the implementation of such strategies is usually beyond the scope of water managers. In recognition of the fact that new physical infrastructure will be needed for food, energy and flood protection and enhanced storage to adapt to climate change, proper measures must be taken in the overall spectrum from planning to operation of such infrastructure. As with all hard approaches, however, whether directed to agriculture, urban or industrial water uses, new or updated water infrastructure may be necessary. It must be noted that this increases the complexity of water management, by virtue of the greater range of actors and issues being incorporated into the decision-making process. This means that an increase in risk and vulnerability is an inherent property of the system by which water is managed.

Twenty-first century water management: The emergence of a range of softer measures

In response to the shortcomings of approaches based on physical infrastructure, there has been a gradual shift towards policies based on institutional reform, incentives and behavioural change (see Chapter 11). These types of approaches seek to reduce the uncertainties and manage the risks related to water resources by embracing more of the non-traditional elements found outside the traditional 'water box'. Here the role of water managers is to inform the decisions taken by others. These include changes in human behaviour related to water usage and revised water governance processes and systems. They constitute a range of generally complementary actions, including cultural values, water pricing, water conservation, water reallocation, economic incentives/disincentives, and social recognition for reducing inefficient water use practices, diversifying water sources and similar activities. As all of these are considered to be out of the box, the *soft path* approach requires significant operational capacity and high levels of coordination among and across various ministries. This is where the 'I' in IWRM becomes of increased importance. Experience over the past half century has demonstrated that *soft* options present considerable potential for addressing water resource issues, but are increasingly complex because of the need to integrate across a range of previously uncoordinated actors. Meaningful stakeholder engagement and participation is likely to grow in significance when developing such measures, placing new demands on institutions and political leadership.

Solutions that embrace a range of softer approaches will make use of forecasting and modelling advances to facilitate more accurate risk assessment, thereby working to increase the resilience and decrease the vulnerability of water systems, while also working across and beyond the traditional range of water resource management to include out-of-the-box actors. This can provide useful information to those water users and stakeholders impacted by water resources management but currently not serviced, such as stockbrokers and institutional investors concerned about undeclared but embedded risk (ACCA, 2009; Chang, 2009; Klop and Wellington, 2008).

The public is often insufficiently informed to comprehend how its use of existing water resources can affect either the quantity or quality of these resources. As a result, the public is not always unaware of ways by which it might contribute to solving the relevant problems. Proper public education and awareness can help engage water stakeholders in needed actions, particularly with regard to reducing water demands and pollution, and it also puts pressure on governments and other decision-makers. At the same time, sustainable and equitable change requires water managers to understand the issues and perspectives of the users and community at the initial stage of implementation, paying attention to their ideas and facilitating institution-building. By identifying differences in power relations and recognizing women's needs and potential contributions, real change can be made in the functioning of water systems, livelihoods and food security. In return, the public can exert pressure, which can result in government agencies and other users and stakeholders refining their water-use policies and programmes.

Implementing non-structural management options usually requires strong operational capacity but limited investments that are often spread over time. Moreover, when non-structural interventions do not lead to the intended goals, contrary to structural measures, they can usually be modified or ended without substantial extra investments. This flexibility is beneficial, but will place increasing demands on political leadership and the management of trade-offs between competing interest groups.

5.1.2 Integrated water resources management

IWRM is defined as a process that 'promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems' (GWP-TAC, 2000, p. 22). IWRM recognizes the interdependencies of multiple components of a regional water resource system: high irrigation demands and polluted drainage flows from agriculture mean less freshwater for drinking or industrial use; contaminated municipal and industrial wastewater pollutes rivers and threatens ecosystems; the slow-onset disaster of uncontrolled decanting of acidic water from abandoned mines; and if water has to be left in a river to protect fisheries and ecosystems, less can be diverted to grow crops.

IWRM implies that all the different uses of water resources are considered together. Water allocation and management decisions should consider the effects of each use on the other, thus taking into account overall social and economic goals, including the achievement of sustainable development targets, health and safety. This also means ensuring coherent policy-making related to all sectors, most notably between decision-makers concerned with national water security, national food security and national energy security. Competing user groups (farmers, communities, environmentalists, etc.) can influence strategies for water resource development and management, with the result that the process becomes more political and less purely technical as integration occurs and a potential basket of benefits emerges (Phillips et al., 2006, 2008). That brings additional benefits, as informed users can often apply local self-regulation in relation to issues such as water conservation and catchment protection (GWP-TAC, 2000). Integrated management contrasts with the sectoral approach where responsibility for drinking water rests with one agency, for irrigation water with another, for energy and mine water elsewhere and for the environment with yet another. Lack of cross-sectoral linkages may lead to uncoordinated water resource development and management that may result in chaos, conflict and waste of resources (CapNet, GWP and UNDP,

2005) and an unsustainable overall picture where components vie for suboptimal solutions at best.

The essential purpose of IWRM is to manage water more efficiently and effectively. IWRM entails the coordination of 'policies, institutions, regulatory frameworks ... planning, operations, maintenance and design standards of numerous agencies and departments responsible for one or more aspects of water and related natural resources management' (Stakhiv and Pietrowsky, 2009, pp. 4–5). Multi-disciplinary and multi-agency coordination and cooperation is therefore an important feature of IWRM.

This edition of the *World Water Development Report* provides an update on the commitment to IWRM made by the international community and countries (see Section 1.3.3). It states that while important developments have been made around the world, the preparation by governments of national IWRM plans and the actual implementation rates of these plans remain unsatisfactory and well behind targets. 'Water management can work effectively (but not necessarily efficiently) in fragmented institutional systems (such as the federally based systems of Australia, Brazil and the United States of America), where there is a high degree of decision-making transparency, public participation, and adequate financial support for planning and implementation. It does not work well in most other cases where these prerequisites do not exist. Setting up the proper institutional framework is the first step toward IWRM' (see Section 11.2).

One of the goals of IWRM is to reconcile economic development and ecosystem maintenance. This is a challenge because economic development goals and environmental needs are associated with different temporal scales, and both have been based on traditional water management concepts that do not always consider the unexpected risks and uncertainties associated with the softer approaches. For this reason, ecosystem goods and services and their valuation are increasingly included in IWRM planning. However, they can also constitute a major source of uncertainty for a variety of reasons.

Workable and sustainable solutions in water management are achieved through *integration*: between land and water management; between the management of different urban water systems; between the water and energy, mining and agricultural sectors; and between construction and operation and maintenance procedures. Integration is generally achieved incrementally in a step-wise process that can be drawn out. In particular, dialogue between stakeholders facilitates integration, which is itself shaped by the context.

"The public is often insufficiently informed to comprehend how its use of existing water resources can affect either the quantity or the quality of these resources."

These processes, as well as dialogue between stakeholders, can also help to address broader issues of coordination and integration outside the realm of IWRM, which arise when water resources, use and management are impacted by actions taken by decision-makers in other, non-water sectors for other objectives, as established by the WWDR3 (WWAP, 2009).

5.1.3 Water resource management under uncertain demands

Hydro-climatologic information about frequencies, magnitude, duration and incidence of precipitation and runoff events ought to be the basic inputs into most water management decisions. They have been combined with more fundamental economic, environmental and socio-economic information and objectives to better inform water management decisions. Land use regulations, economic priorities, trade policies and cost–benefit criteria are among other inputs used to decide between water management options (Stakhiv and Steward, 2009). In all of this, water management now has to account for unforeseeable changes in the nature and timing of population growth, migration, globalization, changing consumption patterns, technological advances and agricultural and industrial developments. These issues were already present, but were for the most part neglected. The looming spectre of climate change has helped to draw attention to their importance, adding a new dimension to the ever-increasing complexity arising from the drivers mentioned above.

As the assumptions emanating from stable-state systems are no longer appropriate, one of the current challenges involves determining the capacities of new infrastructural components for a water resource system whose future inputs or design flows can no longer be predicted or calculated from the historical record. Under conditions of uncertainty it is no longer possible to use today's science, based on yesterday's experience, to predict the needs of the future (Turton, 2007). The challenge of predicting demands during an era of accelerated changes adds to the complexity. Drivers of water also interact among themselves (see Chapter 9), which creates a new set of uncertainties and associated risks, as well as a diverse and complex variety of combinations and possible paths. This may well be beyond the understanding of those dealing with various management challenges. For example, land-use change and urbanization, already resulting in pollution, the sealing of surfaces and a loss of forests and wetlands causes increased runoff, resulting in a higher risk of flooding, sedimentation and eutrophication. Demographic changes, including population growth and changes in consumption patterns and migration, frequently lead to increasing demands for water and food. The growing pressures on water often concentrate in coastal areas, where climate change is expected to have the highest impact. These areas are already under high water stress and increased pressure often results in the salinization of groundwater where rising water in the soil brings diluted salts to the surface, which are not fully flushed away (WWAP, 2009). Growing energy consumption increasingly impacts on water, through biofuel production that requires significant amounts of water; thermal power plants that need huge amounts of water for cooling, adding to the water temperature increase caused by climate change; and biodiversity and water chemistry arising from the acidification of rain due to the sulphur cycle. Finally, the state of infrastructure such as dams and irrigation systems can, if inadequate, lead to major risks of water waste, which exacerbate water stress, as well as to increased risks of major accidents. Both sets of risks can aggravate climate change impacts (UNECE, 2009).

Society in general, and the engineering profession in particular, 'through a historical accumulation of experience, laws, engineering practices and regulations, has defined a narrower acceptable range of "expected" events to which it chooses to adapt – hence, there is the 100-year floodplain for flood insurance purposes; criteria for the design of urban drainage systems for smaller but more frequent events; and dam safety considerations by designing spillways for very low-probability floods, for example a 10,000-year return period. These are societal judgments made on the basis of many factors, including affordability, relative population vulnerability, and national and regional economic benefits. They are not deterministic criteria made on the basis of empirical or simulation modelling. Defining social risk tolerance and service reliability is part of a "social contract" to be determined through the political process coupled with public participation' (Stakhiv and Pietrowsky, 2009, p. 8), which constitutes an element of uncertainty in the Soft Path Approach.

Discounting, a method used to compress a stream of future costs and benefits into a single present value amount, is an important concept, because it can have a major effect on the outcome of the cost–benefit calculation. A high discount rate will favour avoiding the costs of adaptation now, whereas a low discount factor encourages immediate action. Setting the discount rate is therefore basically defining the social welfare function across generations with substantial implications for the decisions taken. To deal with all the uncertainties, scenarios are developed that describe possible futures, depending on, among others, decisions based on societal values. Based on the scenarios, models help to predict the effects of these possible futures for hydrological conditions and help to identify vulnerabilities that water management measures would help solve (UNECE, 2009).

5.1.4 Adaptive management

The complexity of water management, combined with increased uncertainty, both through socio-economic developments and climate change, makes the traditional command-and-control approach less effective. An adaptive approach towards IWRM responds to this. Adaptive management can generally be defined as a systematic process for improving management policies and practices by learning from the outcomes of management strategies that have already been implemented (Pahl-Wostl et al., 2007). It is a continuous process of adjustment that attempts to deal with the increasingly rapid changes in our societies, economies, climate and technologies. In essence, adaptive water management is based on a series of feedback loops being hard-wired into the system, which enable many incremental adjustments to be made before a catastrophic problem manifests. It is learning to manage by managing to learn.

Learning in water management encompasses the range of ecological, economic and socio-political domains in testing the effectiveness of structural and non-structural measures. The quality of the management process in this approach is essential, including the realization that management strategies and goals may have to be altered during the process (Pahl-Wostl et al., 2007). Successful adaptive water management includes some approaches in addition to overall water management (Mysiak et al, 2010):

- It builds on collaborative governance – a joint effort of government, society and science – to ensure that measures will be effective and sustainable. Trust and social capital are important in ensuring that the problem-solving process takes place.
- It is embedded in an 'enabling environment': a political, institutional and legal setting that enables learning and does not hinder adaptive approaches (UNECE, 2009).
- It changes from water supply management to water demand management. The availability of water resources is the baseline, not the demand for water. Improving efficiency of water use will help ensure a sustained supply of water to different uses in times when resources become scarce.
- It pays more attention to non-structural ('softer') water management measures. Legal and policy agreements help to promote more sustainable use of water in all sectors while explicitly considering equity and poverty alleviation measures.
- It recognizes adaptation in water management to changing conditions such as energy and food prices, demographic trends, migration flows, changing production and consumption patterns, and climate change is a long-term continuous exercise, not a one-off set of measures.
- It bases the financing of water management on the valuation and pricing of water resources use without impacting the most vulnerable groups in a disproportional way nor unduly harming local competitiveness.

Implementation of these recommendations is highly demanding, and requires that managers overcome the inertia of traditional approaches and resistance from various actors. The major challenge for authoritative regulatory bodies at local and national levels, however, is to develop a coordinated 'vision of how to implement the ideas, as well as the courage to withstand criticism and to share power with other actors' (Timmerman and Bernardini, 2009, p. 2).

5.2 The importance of water institutions for sustainable development

5.2.1 Institutions: The rules of the game

According to the Nobel economic laureate Douglass North, 'Institutions are the humanly devised constraints that structure political, economic and social interaction'. They consist of both informal constraints (sanctions, taboos, customs, traditions, and codes of conduct) and formal rules (constitutions, laws, regulations, and property rights) (North, 1990, p. 97).

Institutions constitute the 'rules of the game', defining roles and procedures for people, possessing of permanence and stability, and determining what is appropriate, legitimate and proper (see Chapter 25). These 'rules' have evolved organically, responding to history, geography, culture and politics, and reflecting technical advances and the evolution of professional practices and local capacity. Actors other than water managers often dictate the rules of the game for water. In most cases, they are established without water as their central focus and lack recognition of its pivotal importance.

Institutions underpin the management of water resources and the delivery of key services that sustain health, welfare and economic growth. Global water problems can be traced to a deficit of *governance* resulting from a lack of appropriate institutions at all levels, and the chronic dysfunctionality of existing institutional arrangements (Lewis et al., 2005). Water management institutions are part of the broader institutional framework of countries (see Chapters 11 and 25). The potency of this framework will encourage or hinder effective approaches to managing water resources and its related services. Laws, policies, private and public entities, along with stakeholders outside the 'water box', can greatly influence how water institutions behave and perform under normal circumstances.

5.2.2 What institutions do, and why they matter

Water-related institutions function at different scales ranging from the local community to the transnational level, and oversee the allocation, distribution, management, planning, protection and regulation of water resources and services. Institutions define roles and procedures, which determine what is appropriate, legitimate and proper (see Chapter 25). In addition, traditional and contemporary social rules may be applied to water use and management.

Informal water rights systems are not just 'customary', 'traditional' or 'ancient'. On the contrary, they can form a dynamic mix of rules, principles and organizational forms that are highly relevant to contemporary problems. They combine local, national and global rules, and often mix indigenous, colonial and contemporary norms and rights. Local water rights exist in conditions of legal pluralism where rules and principles of different origin and legitimization co-exist and interact (Boelens, 2008).

Aflaj irrigation systems, widespread in many Middle Eastern countries, are an example of one such informal system for allocating water.[1] Clientelism[2] or even corruption can also be viewed as methods for determining the allocation of water resources and services among different sectors and groups. Informal systems can sometimes be assimilated into the formal economy, as in Paraguay, where small informal private drinking water supply systems have been recognized and agreements developed between local governments and small-scale private water vendors. The outcome has been easier control and monitoring of the pricing and quality of service (Phumpiu and Gustafsson, 2008).

In 2010, resolutions by the United Nations General Assembly and the Human Rights Council confirmed that access to safe water and sanitation is a human right (see Section 1.2.4). Member states are required to ensure the progressive implementation of the right to water and sanitation to everybody in their jurisdiction. It is hoped that this will contribute to accelerating much-needed progress in providing these essential services to billions of people who do not currently enjoy them. According to the measurements and standards of the Millennium Development Goals (MDGs), the reports of the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation, and the Global Annual Assessment of Sanitation and Drinking-Water (GLAAS) processes, 884 million people still use unimproved sources for drinking water and 2.6 billion people do not use improved sanitation (WHO/UNICEF, 2010). Measured against the more precise and rigorous standards now defined under the right to water, these figures represent a significant under-estimation. Some estimates indicate that the number of people without access to safe and reliable tap water in their homes is between 3 and 4 billion. The push to increase access to drinking water and sanitation to meet the expectations of the right to water could become a major driver shaping the future development of water services.

5.2.3 Institutions 'fit for purpose'

The second edition of the W*orld Water Development Report* (WWDR2) noted that poor access to water resources and services is not the result principally of water shortages, but of an 'institutional resistance to change' due to a 'lack of appropriate institutions' for managing and securing resources for building both human capacity and physical infrastructure' (WWAP, 2006). For example, some countries, often those with the greatest need, are unable to absorb the current level of aid for sanitation and/or drinking water. These developing countries will need to strengthen their national and subnational systems in order to plan, implement and monitor the delivery of sanitation and drinking water services, especially for underserved populations (WHO/UN-Water, 2010). The WHO/UN-Water GLAAS (2010) document reports that defining appropriate institutional roles and responsibilities remains a challenge for both sanitation and drinking water. Even where national strategies are well developed, government institutions are well coordinated and adequate financing is available, progress in sanitation and drinking water may still be limited by the lack of adequately trained, capable staff and a work environment conducive to effective outputs (WHO/UN-Water, 2010). The WWDR2 referred to confusion in water governance in many developing countries, citing 'a lack of water institutions' and 'a display of fragmented institutional structures' as issues requiring immediate attention. GLAAS 2010 recommends that 'sound policies, allied to effective institutions, are important for optimizing service delivery. Establishing clear roles and responsibilities for the different institutions involved in sanitation and drinking water is also important, if good progress is to be made' (WHO/UN-Water, 2010, p. 2).

A recent business survey – in which firms chose between different types of possible constraints on doing business in the country concerned – showed the constraints imposed by prevalent institutional systems (Figure 5.1). Institutional and governance-related issues such as bureaucratic performance and corruption control appear to rank higher than quality of infrastructure in regions like sub-Saharan Africa and South Asia.[3] The implication is that investment in water development requires a combination of soft and hard measures, with priority being given to institutional reform – with emphasis on good governance, effective regulation, strong operational capacity and control of corruption – in many cases.

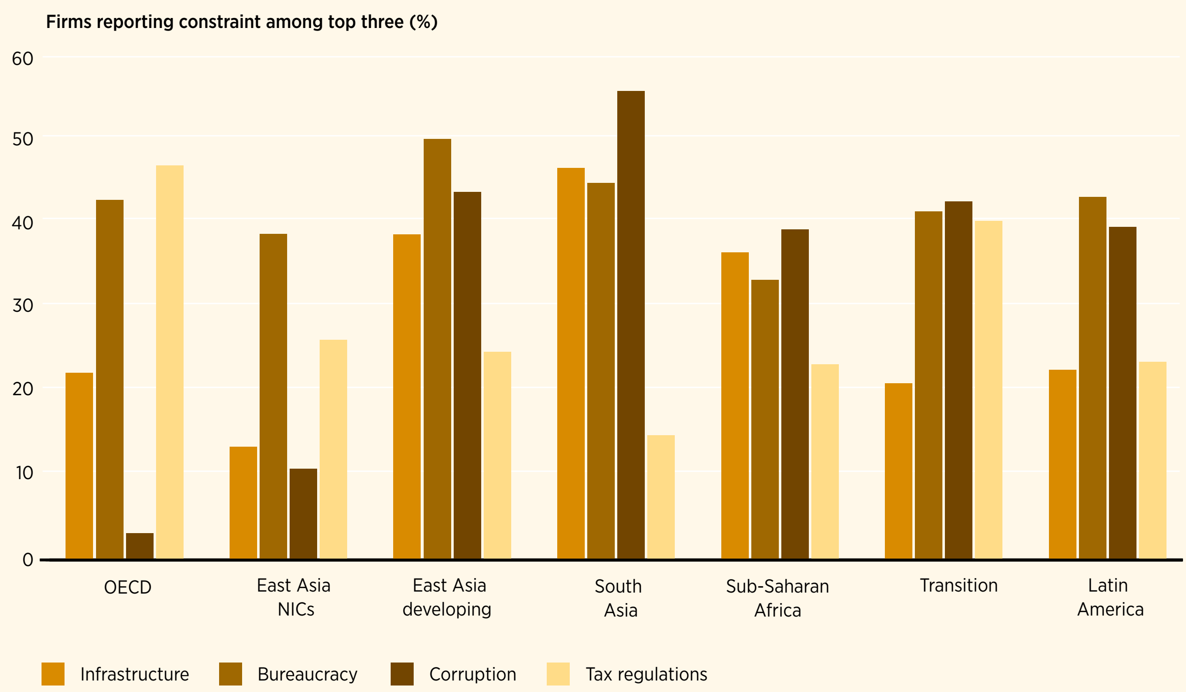
Countries show great variation in institutional design. In some countries and regions, for example China, the Middle East and North Africa, water institutions reflect strong government steering, top-down management and hierarchical control. Elsewhere, a greater diffusion of powers can be found among government, civil society and markets, with varying levels of emphasis on features such as transparency, multi-stakeholder participation and accountability. Irrespective of their type, institutions govern similar issues of resources allocation, quality protection, planning and so on. Allocation is becoming a widespread issue, particularly in countries such as those in the Middle East, which have already developed easily accessible water, and where additional water provision will come at a high cost. Currently, many countries in the region are using up to 90% of their water for irrigation, whereas agriculture is contributing less and less to GDP, and more economically vibrant sectors often face severe water constraints (Beaumont, 2005).

Effective institutions can reduce natural, economic, technical and social uncertainties. For example, the successful negotiation of tensions and conflicts over shared waters will reduce uncertainties for the parties concerned and lead to more rational water use and allocation. Effective water institutions fulfil several purposes:

Define roles, rights and responsibilities at different scales. 'Institutional arrangements define who controls

FIGURE 5.1

Key constraints to doing business in several geographic and economic regions



Note: The question posed to the firm was 'Select among the above 14 constraints the five most problematic factors for doing business in your country'.
Source: Kaufmann (2005, fig. 2, p. 85).

the resource and the extent of a property regime' (Ananda, et al., 2006). Institutions play a vital role in establishing the working rules of rights and duties, and in fixing the relationships of multiple or co-users to one another and to a specific natural resource. In Kenya, the recent water sector reforms have clearly delineated the institutional arrangements for the roles and responsibilities of agencies involved both in service delivery and water basin management. The reforms have, for example, encouraged a sector-wide approach to planning (SWAp),[4] which promotes good practice for partnerships, conduct, investment planning, coordination, monitoring and decision-making – all aimed at improved service delivery and accountability within and among sectors.

Determine restrictions and provide for mediation of conflicts. Institutions set certain individual and collective restrictions to water use: who can use what water, how much, when and for what purposes. A widening gap between water supply and demand intensifies competition and conflicts between water users, regions and economic sectors. This puts pressure on institutions dealing with resource allocation and management, and heightens the importance of mechanisms which deal with conflicting interests through economic incentives. The Mekong River Basin illustrates the complex relations between states and rivalry among water institutions. Transboundary water conflicts have generally been contained in this basin, but the growth of water scarcity due to environmental and developmental factors could lead to major conflicts in the future, driving the reform of regulatory and allocation mechanisms. In some instances, water conflicts have accelerated institutional change.

Reduce transaction costs and stimulate investments. Institutions underpin increased and more effective investments. Poor institutions pose increased investment risk and affect the competitiveness of countries and the performance of their firms. Effective institutions lower transactions costs, namely the various costs incurred in making an economic exchange and taking part in a market – costs such as those for search and information, bargaining and decision-making, and policing and enforcement.

5.2.4 Water institutions: Current status and future challenges

Water encompasses a wide range of sectors and uses throughout its natural cycle, at different scales, and with no overall unified system of management or governance. Even if some coherence could be brought into water management – in whatever sense this term is used (e.g. from applying the IWRM paradigm) – important influences on water would continue to be exerted from forces 'outside the box', such as national policies on regional development, international trade, tourism, housing, energy, agriculture and food security, environmental protection and so on. Due to these complexities, it is difficult for water institutions to adapt to current and future risks and uncertainties, and to develop any kind of consistent approach.

The diverse structure of water management in dealing with various resource and use/service-related issues is reflected in the complexity and fragmentation of the institutions that exist to govern and manage it. It is rare to find a 'ministry of water' (as in Bolivia, India or Tanzania) dealing with all aspects of the sector. It is more common to have separate ministries responsible for water resources, irrigation, environment, power, transport, health, urban water supply, rural water, and so on. Each of these subject areas impinges on water, yet each typically has separate ministerial responsibility and administrative structures, with financing usually determined independently of other interested parties.

The 'rules of the game' for water management are set in a diffuse institutional environment, where imminent decisions to be taken in response to climate change or environmental sustainability are heavily influenced by the specific needs of other sectors, with water a secondary consideration. Making coherent decisions on such momentous issues, with the various trade-offs they imply, will call for some institutional machinery linking decision-makers in key sectors with those responsible for water management. A wider group of stakeholders needs to be involved in the rule-setting process (Figure 10.2).

While some countries have made progress toward effective water governance, the success of institutional reform has been mixed: many countries have not overcome their shortcomings in governance, financial and capacity areas. For example, reforms in Ghana, India and South Africa came as part of a wider move to economic reform, but have not been uniformly successful.

Some common features of institutional reforms are the adoption of an IWRM framework, including water resources planning, the establishment of river basin management authorities, the encouragement of multi-stakeholder engagement, and the use of cost-effectiveness, cost recovery and cost–benefit analysis to determine investment priorities. Rights-based approaches to water services and the inclusion of integrity and accountability criteria are other recent developments.

The subject matter of water management and policy-setting is continuously being redefined due to cultural, economic, political, social and environmental changes. These shifting forces pose various challenges for institutional reform, some of which are detailed here:

Integration. The institutions governing water in its many facets need to be sufficiently comprehensive, and the policies for water management need to be coherent enough, to deal effectively with looming problems. A case in point is climate change, which is a major current driver of institutional change. Water will be a primary medium through which climate change impacts will be experienced by various sectors, and the way the process is managed will shape sustainable development and poverty reduction efforts. Changes in water availability and demand will worsen existing stresses in sectors such as health, food production, sustainable energy and biodiversity, while water-related risks due to extreme events, such as flash floods, storm surge and landslides, are set to increase. Effective institutions must therefore be able to accommodate the re-allocation of water in response to changes in its availability. The institutional response should include promotion of cost-effective conservation measures and efficiency enhancements under effective water demand management practices. The strengthening of local institutions and strengthening of social networks is an integral part of successful adaptation (Box 5.1).

Institutions should be sufficiently flexible and adaptable to account for uncertainties in both water supply and demand. A degree of formal recognition and assimilation might be justified in the case of informal water service providers, who typically deal with marginalized water users whose needs are not met by established formal supply networks.

Integrity, transparency and accountability. Attempts to tackle mismanagement, corruption, bureaucratic inertia and red tape can prove a major stimulus for institutional change. Corruption is a core symptom of poor governance, which distorts investment, increases transactions costs and discourages innovation. Petty corruption has a particular impact on the poor and disempowered. This calls for, among other things, the enforcement of regulations on the performance and expenditure of service providers. In most developing countries, such regulation is either weak or absent. Existing systems of monitoring, policing, sanctions and incentives are not applied on a systematic basis and are often derailed due to clientelism and corruption (Box 5.2).

Capacity development and resources. The delegation of responsibility to local water agencies should be accomplished by corresponding transfer of powers, tools and resources – in short, capacity. Any delegation should be based on careful analysis to help determine the appropriate level for decentralization or centralization, in accordance with technical considerations and economies of scale and scope. Because of the low profile and unfashionable character of water management and service agencies, their gradual loss of resources and capacity has gone largely unnoticed. This trend needs reversing if the agencies in question are to address the far-reaching changes required.

BOX 5.1

Adaptation to water stress in the Greater Himalayan Region

Five case studies from the Greater Himalayan Region looked at situations where people are responding to too much water (floods, water logging) or to too little water (drought, water stress). The regions examined were the dry mountain valleys of Chitral in Pakistan; the middle hills in Nepal; the flood plains of Bihar, India in the Koshi basin; the flood plains of Brahmaputra in Assam in India; and the hill areas of Yunnan, China.

Some of the key findings for adaptation comprised a mix of strategies to develop diversification of livelihoods and to make use of and strengthen local institutions and social networks. Cultural norms and rules affect people's adaptive behaviour, and need to be considered, but they are dynamic and can shift over time in response to different needs. In addition, it was acknowledged that national institutions and policies strongly affect people's ability to adapt at the local level, but the national level is rarely informed by adaptation concerns and priorities.

Source: ICIMOD (2009); see also Chapter 25.

Generating adequate and sustainable funding. Many water institutions in developing countries are weak and under-financed (Dinar and Saleth, 2005). New funding is required for institutional capacity-building and adaptation, but it is equally important to use existing funding more efficiently. Most water funding goes to infrastructure development and less is invested in operations and maintenance and developing institutions and human capacities. Of the 11 reporting countries in the 2009–2010 CSO and GLAAS country surveys, the contribution of recurrent expenses, including salaries, non-salaries and urban subsidies, to total expenditures for sanitation and drinking water ranged anywhere from 13% to 78% (note that only internal sources of financing for government expenditure are included) (WHO/UN-Water, 2010). Both public and private sector funding should be enhanced, if necessary, through innovative funding approaches.

BOX 5.2

Development of regulatory accounting in Latin America

Manipulation of accounting is a serious concern in the regulation of public utilities and regulators usually devote considerable attention to the methods of accounting used by the utilities they regulate. In general, a regulator cannot do an effective job if it does not have the authority to define the accounting systems under its jurisdiction. When water utilities were opened up to private investment in the 1990s in Argentina, it became necessary to develop a regulatory framework that would induce them to work towards the objectives set forth by the State. The Aguas Argentinas system was one of the first experiences of regulatory accounting for water and sanitation service providers in the region. The following lessons were learned about implementing this effective regulatory tool:

- To the extent possible, the project should be approached as a joint undertaking between the regulator and the regulated entity, with dedicated, multidisciplinary teams on both ends.
- Contributors to the project should be brought on board as early as possible, including technical, operational, commercial, administrative and information technology personnel to ensure effective collaboration and support.
- It should be understood that the modifications to information systems and procedures involved in the implementation of regulatory accounting take place in large, existing companies, which limit discretional authority and can increase the time it takes to implement changes.
- In order to foresee unintended consequences and have time to make any necessary adjustments, the possible effects of the project on the work culture in both the utility company and the regulatory agency should be taken into account.

Experience both at home and abroad indicates that information asymmetry is also present in the regulation and oversight of publicly owned service providers. Accordingly, once the Aguas Argentinas contract was revoked in 2006 and services were transferred to the largely state-owned Agua y Saneamientos Argentinos (AySA) in 2006, the new regulatory framework stipulated that the public company also had to implement a regulatory accounting system.

Sources: Jouravlev (2004) and Lentini (2009a,b).

Conventional water planning is too rigid to meet the challenges ahead, which require the development of adaptive governance frameworks and institutions. Calls have been made for more resilient institutions and approaches (GWP, 2009). In fact, the institutions that govern the management and use of water are not immutable, and have the capacity to change in response to circumstances, particularly crises. Many reforms are born out of conflict (Box 5.3)

Institutional reforms may impose transitional costs of their own, offsetting some of their expected benefits. In Kenya, for example, some stakeholders see institutional changes such as the introduction of sector-wide approach to planning (SWAP) as potentially increasing bureaucracy and complexity and removing decision-making further from the grassroots level. There is some concern regarding the potential for transaction costs to rise with SWAP, and some non-governmental organizations (NGOs) fear that SWAP may reduce their funding levels. These institutional reforms may require higher levels of transparency and higher government-monitoring capacity, both weak points in the sector at present.

Institutions that develop in the water sector inevitably reflect those in wider society. The privatization of water assets in England and Wales, and Chile, and the growth of markets for water in the latter, developed within a political and legal context favourable to the transfer of assets into private management and ownership. The active use of water tariffs, and the use of water markets for allocating scarce supplies, is likely to be more feasible in economies with widespread involvement of private producers, than in countries with a strong 'statist' tradition. The precise balance of public and private agencies in the management and delivery of water services differs from country to country – but almost always with the preponderance of the public sector – reflecting a mix of political, ideological and practical factors. It is important to underline that empirical evidence from developed economies reveals that there is little justification for a general presumption in favour of either type of ownership, and case by case evaluation of the various trade-offs is therefore in order (Renzetti and Dupont, 2003; Vickers and Yarrow, 1988).

Against a background of increasing risk and uncertainty, there is an argument for allowing different institutional models to coexist, which could increase resilience and the potential for both policy and technological innovation.

5.3 Institutional knowledge and capacity

5.3.1 The importance of knowledge assimilation and transfer

Water-related problems are commonly the result of ineffective institutions and inadequate water management. To improve water management requires comprehensive skills and training in, for example, engineering and infrastructure maintenance, financial and institutional administration, and policy analysis. Another valuable source of knowledge is experience gained by local water professionals from hands-on management. This local knowledge often goes unrecorded or even unrecognized. Importantly, local managers are aware of many risks and uncertainties related to the water system on which they operate, and they are often the first to identify new issues and problems, as well as their solutions. Local solutions are often workable as they reflect local and indigenous practices and knowledge, and are aimed at meeting local priorities. Local knowledge should be captured and communicated to decision-makers at higher levels, to inform policy formulation at the national level. This also process allows lessons learned to be widely applied, builds the capacity of local institutions and civil society, and empowers local actors.

Commonly, capacity is defined as ‘the ability or power to do, or understand something’. UNDP defines capacity as the ability of individuals, groups, institutions and organizations to identify and solve development

BOX 5.3

Water conflict as an agent of change

Many recent changes in the governance of water and river basins have occurred as an outcome of conflict. In Australia, long-standing conflicts between environmentalists and farmers in the Murray–Darling Basin form the historical backdrop to the Landcare movement and to multi-stakeholder forums for managing water in its basin context. Over an even longer period, competing demands of states have served as the basis for institutional development of the Murray–Darling Basin water management framework. Conflicting visions of catchment management (for example, more and less participatory models) have shaped institutional approaches in New South Wales.

Conflict avoidance can itself be a driver for innovation in water governance. In South-East Asia, the spectre of resource-based conflict between the countries sharing the Mekong River has been a strong driver for cooperation through the Mekong River Commission, and an important justification for official assistance to the Commission. The Se San issue is a case in point. The impacts of the Yali Falls Dam in Viet Nam on downstream riparian communities in north-eastern Cambodia left indigenous minorities from a less powerful country having to deal with the impact of water resource development by the government of a neighbouring more powerful country. While not always able to deliver for local communities, such river commissions can generate improvements and innovative methodological approaches, such as the recently published rapid basin-wide assessment tool.

In Thailand, conflict has arisen over the drafting of a national water law, leading to a more robust public discussion of water legislation and governance issues such as water-pricing options and the creation of an inclusive national policy agenda. This has slowed down reform, compared with the process in Lao People’s Democratic Republic and Viet Nam, whose water laws were passed by their respective national assemblies in 1997 and 1998 without much public discussion. However, even though there was limited public debate over the draft water law in Viet Nam, it went through more than 20 revisions and was extensively debated in the national assembly before eventually being passed.

Source: Boesen and Munk Ranvborg (2004). For more information see http://www.mrcmekong.org/news-and-events/news/innovative-tool-for-mekong-basin-wide-sustainable-hydropower-assessment-launched/

> "Knowledge needs to be multi-disciplinary, based on an understanding of society and nature, and able to facilitate integrated approaches."

problems over time (UNDP, 1997). According to OECD-DAC GOVNET (2006, p. 12), capacity-building means a 'process whereby people, organisations and society as a whole unleash, strengthen, create, adapt and maintain capacity over time'. Internationally, capacity-building, or capacity development, is essential to meet the MDGs (Pres, 2008). It implies funding and resourcing of managerial systems to enable institutions to make and implement policies that lead to the effective and sustainable use of water. The ability to continue acquiring new knowledge is essential for improved performance and adaptation to changing physical and social conditions.

The balancing of 'community focus' and the 'technical approach' calls for strong intellectual leadership and authority, and striking a balance between bottom-up and top-down approaches. However, it is important to keep in mind that an attitude focused on applying knowledge is the most important element of capacity development.

5.3.2 Transforming institutions to become more effective

The water supply and sanitation sector has a low priority in many developing countries, where investments in health and education are often prioritized. Furthermore, 'since 1997 the proportion of development aid allocated to sanitation and drinking water fell from 8% to 5%, while development aid allocated to health increased from 7% to 11.5% and that for education remained steady at around 7%' (WHO/UN-Water, 2010, p. 15). However, under-investment in both infrastructure and human resources leads to poor water management, which then commonly leads to water-related diseases (see Section 4.1). These diseases are among the worst killers in developing countries, where the poorest segments of the population are often hit hardest (Jønch-Clausen, 2004). The 'impact of diarrhoeal disease on children is greater than the combined impact of human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS), tuberculosis and malaria' (WHO/UN-Water, 2010, p. 2). Therefore, there is a great need to strengthen water-related institutions to increase their effectiveness. Since the 1990s, capacity development has become a favoured approach to this end (OECD DAC GOVNET, 2006; Pres, 2008).

Capacity development demands a holistic approach through which people, organizations and societies continually mobilize, maintain, adapt and expand their ability to manage their own sustainable development (Batz, 2007). Unfortunately, conventional methods of water management are often not sufficient to deal with highly dynamic systems (Timmerman et al., 2008). A transition from these conventional methods toward management based on learning rather than only control, and inclusion of the human dimension as an integral part of the management system, is required. It has therefore been suggested that IWRM should be based on an adaptive water management (AWM) approach (see Section 5.1) – 'a systematic process for continually improving management policies and practices by learning from the outcomes of implemented management strategies' (Pahl-Wostl, 2007, p. 51). The reform requirements are different for each institution, depending on its core functions and mandates. Furthermore, each country and region has its specific characteristics and requirements with respect to its water resources situation and institutional framework (Hamdy et al., 1998). This implies that there are no generic solutions, and that problem-solving and institutional arrangements must be tailored for each country and region to meet its own specific needs and conditions.

Water institutions are still largely technology and water supply-driven. Conventional knowledge and capacity is commonly centred around disciplinary knowledge, based on technological know-how and natural science. Much of the information required is physical, pertaining to hydrology, biology, geology and other biophysical disciplines (Chambers, 1997). This type of conventional technocratic knowledge and capacity is important, and will remain necessary for water agencies and decision-makers. However, to improve the effectiveness of these institutions, the emphasis has to change from technological solutions to management of processes and people, involving inclusive decision-making and bottom-up approaches (Tropp, 2007).

BOX 5.4

Enhancing adaptive capacity in the Mekong Basin

In 2000, the Mekong Delta faced its worst floods in 40 years. About 800 people died, 9 million were affected, and the costs of damages reached over US$455 million. Since then, a range of initiatives have been implemented under the Flood Mitigation and Management Programme (FMMP). These include flood forecasting capacities, best practice guidelines for integrated flood risk management, guidelines for integration of flood preparedness plans in district and provincial planning processes, flood-probability mapping and land-use zoning, and an annual Mekong flood forum.

The FMMP's 2009 Flood Report highlighted the implications of climate change specifically for flood risk. Climate change was also a key theme at the FMMP's 2010 annual Mekong Flood Forum. The Forum promotes learning across the Mekong basin. It provides governments and others involved in the programme with the opportunity to gather data on changes in flow regimes and flood risks at different scales and to explore implications and responses by sharing experiences. For example, the Asian Disaster Preparedness Centre (ADPC) is providing lessons on integrating flood risk management at district and provincial scales across countries with decentralized disaster management systems facing similar challenges.

At a national level ADPC's participation in Cambodia's national Disaster Risk Reduction (DRR) Forum, comprising national NGOs and the Government Disaster Management Committee, has been a source of learning on approaches to DRR for both ADPC and the Mekong River Commission (MRC). It has also acted as a channel for linking local-level pilot schemes to national disaster risk management (DRM) policy processes. The MRC also hosts many regional summits and exchange visits to promote information sharing and learning across the basin. Increasingly, the programme is promoting dialogue with civil society organizations and experts outside MRC. A Mekong panel on climate change is due to be established under the Climate Change Adaptation Initiative (CCAI) for continuous learning and reflection on climate change in the region.

Source: Mitchell et al. (2010).

Knowledge needs to be multi-disciplinary, based on an understanding of society and nature, and able to facilitate integrated approaches.

The involvement and empowerment of all stakeholders is therefore required to make water institutions more effective. Coordination between institutions is necessary to achieve water resource management goals, as is awareness-raising and education for all stakeholder groups, from local communities to politicians. An example of an institution built on the involvement of all stakeholders is the basin (or watershed) management committee. Basin management committees are central to the IWRM approach, providing a forum where stakeholder groups can communicate their views and concerns regarding water resources management within the basin (Jønch-Clausen, 2004; see Dourojeanni, Jouravlev and Chávez, 2002 and Dourojeanni, 2001 for region-specific examples and issues).

BOX 5.5

Political leadership as a driver for better water management outcomes

In recent years there has been an increase in the number of women appointed as water and environment ministers in developing countries. This has been a major driver in improving long-term water security and more equitable access to water for domestic and productive purposes. For example, water ministers such as Maria Mutagamba of Uganda, and Buyelwa Sonjica (former Minister of Water Affairs) and Edna Molewa (Minister of Water and Environmental Affairs appointed in 2010) of South Africa have used a form of affirmative action to improve access through women's empowerment in Africa. All three ministers have served as Chair of the African Ministers' Council on Water (AMCOW), and have been leading the effort to bring more women into water management in Africa, and indeed in other regions through the Women Leaders for the Water, Sanitation and Hygiene (WASH) programme of the Water Supply and Sanitation Collaborative Council (WSSCC). In September 2010, AMCOW launched its Strategy for Mainstreaming Gender in Africa's Water Sector, 2010–2014, which provides guidelines for affirmative action to get women involved in water and sanitation management. In Lesotho, South Africa and Uganda, these affirmative action programmes provide special bursaries and incentives to train women for water and sanitation-related careers, including science and engineering.

Source: Brewster et al. (2006). For more information see http://www.amcow.net

For basin management committees to be able to contribute to the decision-making process, there needs to be a clear mandate outlining the roles and responsibility of the institution. Sufficient funding must also be allocated to allow the committee to fill key positions and to actively contribute to the management of the basin. There is a need for a solid information base providing up-to-date biophysical, societal, financial and technical information, which will provide the basis for monitoring, evaluation and decision-making. Finally, adequate human capacity among all involved is essential to allow all stakeholders fair representation, and to enable the committee to contribute meaningfully to management and decision-making at all levels.

Water professionals can serve as facilitators and knowledge-brokers, able to engage with stakeholders at all levels and build bridges between them. They can assist local communities, user associations, businesses, local governments and other stakeholders in better articulating their concerns and priorities, as well as sharing insights and experiences. They can also assist in articulating demands. For example, in Namibia, one central element of the capacity-building component of the IWRM plan is for the government to establish performance support teams. These are teams of water professionals that provide hands-on support to local authorities for such tasks as establishing water meter replacement policies and assisting with leak detection and repair, plumbing and general water reticulation maintenance. This is undertaken in close cooperation with the technical and administrative staff at the authority to ensure capacity development and ownership (MAWF, 2010*b*). In Namibia, the concept of performance support teams is implemented as an integral part of the IWRM plan. However, this concept can be applied regardless of whether a country adopts IWRM. The main focus of the support team is to provide hands-on support to institutions and departments to improve their capacity to do a better job.

While traditional technical knowledge and the capacity to manage water resources remains important in the context of AWM, the ability of water institutions and management actors to absorb, adopt and implement new forms of management is dependent upon additional knowledge and capacities. In AWM, capacity development refers to the development of the knowledge, skills and attitudes necessary for management actors and professional organizations to increase their *adaptive capacity* and create institutions that are flexible and responsive enough to support them in the context of increasing risks and uncertainty (van Scheltinga et al., 2009). Box 5.4 provides an example

BOX 5.6

Forum for integrated resource management (FIRM): An example from rural Namibia

The FIRM is an approach giving rural farmers living on communally managed farmlands a tool allowing them to be in charge of their own development (Kruger et al., 2003). In the centre is a community-based organization (CBO) of rural farmers or a water point committee taking the lead in organizing, planning and monitoring their own activities and development actions while coordinating the interventions of their service providers. Service providers include traditional authorities, government or private extension services, NGOs, other CBOs, and short or long-term projects or programmes. ...

The key element of the FIRM approach is the collaborative planning, implementation and monitoring process led by the CBO representing the community involved (Kambatuku, 2003). This usually takes the form of an annual or semi-annual meeting to which all CBO members and associated service providers are invited. During the meeting, the vision, goals and objectives of the community are reviewed and either reaffirmed or revised. Results obtained from formal or informal monitoring of the previous year's plans and activities are thoroughly discussed and lessons learned are extracted. This analysis serves as the basis for the next step of the annual meeting: operational planning for the coming year. During this process, the various service providers commit themselves, within their mandate, to providing specific support to the community based on the community's own agreed objectives. This approach ensures that services provided by mandated service providers and project partners contribute to the agreed needs and wishes of the CBO and the greater community. It also minimizes the amount of time needed by communities to meet with their service providers, and further ensures ownership by communities of the interventions that take place in their area.

Source: Reproduced from Seely et al. (2007, p. 112).

of good practice for enhancing the adaptive capacity at different levels.

Gender-sensitive approaches in transforming institutions is another important key to success, as exemplified in Africa (Box 5.6).

5.3.3 Information and communications systems

For water managers to be able to adapt to change or to be prepared for uncertain future change, they need access to new information, and they need the capacity to process the information and implement changes based on their new knowledge (Pahl-Wostl, 2007). Local managers having access to consistent, timely and reliable information – in a format that is meaningful to them – empowers them to take part in decision-making, and to hold service providers and government more accountable. Information and communication systems (ICS) can be particularly useful to facilitating the sharing of information and knowledge at local, river basin, national and to some extent international levels. At the national level, it is essential to establish sustainable ICS frameworks for capturing, storing and disseminating data, information and knowledge to all stakeholders in the water sector. This significantly contributes to improved decision-making regarding water resource management (MAWF, 2010*a*). At the community level, concrete steps towards sharing information and knowledge, contributing to improved decision-making and resource management, can include creating dialogue platforms involving local stakeholders and their assisting service organizations, (e.g. government institutions, extension services, NGOs and other service providers). Box 5.6 presents an example of such a platform – the Forum for Integrated Resource Management (FIRM). The focus of such a community-driven forum is to plan and make informed decisions rather than dispute resolutions.

Scientific research – physical, technical or social – should ideally contribute to improved water resources management. Scientists need to 'disseminate results and communicate their findings in a way that can be understood and readily implemented by policy-makers, politicians and communities. At the same time, they must learn from experiences gained through implementation by users at all levels' (Seely et al., 2008, p. 236). A range of information communication technology (ICT) tools exist to communicate scientific knowledge effectively, including animations and role-plays. 'Hot' water issues can be used to raise public awareness and understanding. The

"Local managers having access to consistent, timely and reliable information – in a format that is meaningful to them – empowers them to take part in decision-making, and to hold service providers and government more accountable."

construction of the Øresund bridge between Denmark and Sweden illustrates a successful application of ITC. The project involved experts from many disciplines, who had to work in partnership with different stakeholders, including the public. The establishment of an ICT-based real-time water information service allowed all stakeholders to monitor the progress of the project and results from different scenarios and participate proactively in the decision-making process (Velickov, 2007). According to Seely et al. (2008), several key factors contribute to making the connections necessary for facilitating application on all levels of research advances. These include translation, information dissemination, communication, communication platforms, boundary organisations and leadership contributing to knowledge, motivation and capacity. Encouraging 'research brokers' and science journalists to engage in interdisciplinary policy-making debates can facilitate this process. An assessment of the roles of Danish science journalists and communicators in informing the public and policy-makers shows that science communicators play an important role in providing the public with a greater and increased understanding of scientific knowledge, and putting sciences in a broader social and democratic context of value to decision and policy-makers (Hvidtfelt-Nielsen, 2010).

5.3.4 Knowledge and capacity development: An ongoing process

'Recent evaluations have demonstrated that water-related development projects are now decidedly more effective and sustainable than before the mid-1990s (World Bank, 2010). This can be attributed in large part to stronger institutions, better governance, and better technical and managerial competence in the developing countries whose capacity has been strengthened' (Alaerts and Dickinson, 2009, p. 29).

With appropriate mentors providing hands-on experience, incremental capacity development can start taking place almost instantaneously. However, it is important for individuals, organizations and institutions to recognize that capacity development is an unending process, as knowledge and the environment, natural, social and economic, in which water management is taking place is constantly changing. A key element of capacity development is instilling the concept of continuous change and how to adapt to and deal with evolving situations and conditions. Box 5.7 illustrates how the development of knowledge and capacity is a step-wise, ongoing process and touches upon several elements previously described in this section.

BOX 5.7

Social learning and adaptive water resources management in the South Indian Lower Bhavani

The Lower Bhavani Project (LBP) has 84,000 ha as a command area located in the South Indian state of Tamil Nadu. Among others, the most significant uncertainty factor is rainfall variability. The LBP suffers from water scarcity and high unpredictability, leaving the farmers to endure and adapt to frequent seasons without canal supply. The farmers have proved to be able to learn and adapt over the years. The large-scale development of wells in the area shows how the farmers have successfully managed to increase water availability to balance water scarcity during seasons without supply. The farmers have also acquired a capacity to swiftly adjust the cropping pattern to the highly unpredictable variability of seasonal canal water supply, and also to entirely rainfed conditions.

The entire chain of system changes shows that social learning is taking place within the LBP system. The different actors have together learned how to optimize the system within the limits of the technical infrastructure, the reservoir capacity and the canal discharge capacity, and the variability in available supply decided by the erratic precipitation. The way farmers have learned and been inspired by each other, like the benefits from conjunctive groundwater use and the acceptance of irrigated dry crops, are examples of social learning between actors at short timescales. On a long-term perspective, all the actors in the LBP system have learned from the environmental responses and each other's behaviour. Together they have contributed to the alteration of governance structures and have developed new innovative practices without being bound and limited by the original use of the existing technical infrastructure. All actors, thus, live with change, but few appear to remember what caused the change in the system and why it happened.

The AWM analysis shows that the LBP system has, over the years, fulfilled the criteria of a complex adaptive system more and more. Several changes have taken place and earlier mistakes or failures have been addressed in a stepwise way to reach the present complex human-environment technological system. The system proves to have an adaptive capacity and farmers not only cope in an ad hoc manner, but also have developed different adaptive strategies. To a large degree, the system fulfils the requirement of an adaptive regime. Social learning takes place at both system level and at the individual farmer's level. The uncertainty factors have been considered in a stepwise way during the system change cycles and have been included in the system design. The system has moved from a top-down project to a management system with multiple actors. Both farmers and the authorities have learned over the years and now have better possibilities to interact.

Source: Adapted from Lannerstad and Molden (2009, pp. 26–27).

Notes

1 *Aflaj* are traditional systems, sometimes with formal legal status, setting traditional practices for allocating water between different periods of time and between users. They contain a process of users' rights based on ownership or rental (see Chapter 25).

2 Clientelism refers to a form of social organization common in many regions and characterized by patron–client relationships. In such places, relatively powerful and rich 'patrons' promise to provide 'clients' with jobs, protection, infrastructure, and other benefits in exchange for votes and other forms of loyalty, including labour.

3 It is acknowledged that there can be wide variations between countries within a region. The results of the survey should be perceived as relative, not suitable for regional comparison.

4 An approach whereby donors agree to pool their resources to support a specific sector and follow common policies, including the use of national government procedures for the disbursement and accounting of aid funds.

References

Alaerts, G. J. and N. L. Dickinson (eds). *Water for a Changing World: Developing Local Knowledge and Capacity.* Proceedings of the International Symposium 'Water for a Changing World Developing Local Knowledge and Capacity', Delft, The Netherlands, 13–15 June 2007. Abingdon, UK, Taylor & Francis.

Allan, J. A. 2000. *The Middle East Water Question: Hydropolitics and the Global Economy.* London, IB Tauris.

ACCA (Association of Chartered Certified Accountants). 2009. *Water: The Next Carbon?* London, ACCA.

Ananda, J., Crase, L. and Pagan, P. G. 2006. A preliminary assessment of water institutions in India: An institutional design perspective. *Review of Policy Research,* 1 July. http://business.highbeam.com/2032/article-1G1-152886460/preliminary-assessment-water-institutions-india-institutional

Bakker, M. H. N. 2007. *Transboundary River Floods: Vulnerability of Continents, International River Basins and Countries.* PhD thesis. Oreg., US, Oregon State University.

Batz, F. J. (ed.) 2007. *Capacity Development in the Water Sector: How GTZ Supports Sustainable Water Management and Sanitation.* International Water Policy Project. Eschborn, Germany, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

Beaumont, P. 2005. Water institutions in the Middle East. C. Gopalakrishnan, C. Tortajada and A.K. Biswas (eds) *Water Institutions: Policies, Performance and Prospects.* Berlin, Springer.

Boelens, R. A. 2008. *The Rules of the Game and the Game of the Rules: Normalization and Resistance in Andean Water Control.* PhD thesis. Wageningen, The Netherlands, Wageningen University.

Boesen, J. and H. Munk Ravnborg (eds). 2004. *From Water Wars to Water Riots? Lessons from Transboundary Water Management.* Danish Institute for International Studies (DIIS) Working Paper no 2004/6. Copenhagen, DIIS. http://www.diis.dk/graphics/Publications/WP2004/jbo_hmr_water.pdf

Brewster, M., Herrmann, T. M., Bleisch, B. and Pearl, R. 2006. A gender perspective on water resources and sanitation. *Wagadu,* Vol. 3, pp. 1–23.

Brooks, D. B., Brandes, O. M. and Gurman, S. (eds) 2009. *Making the Most of What we Have: The Soft Path Approach to Water Management.* London, Earthscan.

Chambers, R. 1997. *Whose Reality Counts? Putting the First Last.* London, Intermediate Technology Publications.

Chang, S. A. 2009. A watershed moment: Calculating the risks of impending water shortages. *The Investment Professional,* Vol. 2, No. 4. New York, New York Society of Security Analysts. http://www.theinvestmentprofessional.com/vol_2no_4/watershed-moment.html

CapNet, GWP and UNDP. 2005. *Integrated Water Resources Management Plans.* Training Manual and Operational Guide. Issued with the support of the Canadian International Devlopment Agency (CIDA), within the framework of the Partnership for African Waters Development (PAWD) programme. http://www.cap-net.org/sites/cap-net.org/files/Manual_english.pdf

Coetzee, H. 1995. Radioactivity and the leakage of radioactive waste associated with Witwatersrand gold and uranium mining. B. J. Merkel, S. Hurst, E. P. Löhnert and W. Struckmeier (eds) *Proceedings Uranium Mining and Hydrogeology 1995, Freiberg, Germany: GeoCongress 1.* Köln, pp. 34–9.

Coetzee, H., Winde, F. and Wade, P. W. 2006. *An Assessment of Sources, Pathways, Mechanisms and Risks of Current and Potential Future Pollution of Water and Sediments in Gold-Mining Areas of the Wonderfonteinspruit Catchment.* WRC Report No. 1214/1/06. Pretoria, Water Research Commission (WRC).

Dalcanale, F., Fontane, D. and Csapo, J. 2011. A general framework for a collaborative water quality knowledge and information network. *Environmental Management,* Vol. 47, No. 3, pp. 443–55.

De Stefano, L., Duncan, J., Dinar, S., Stahl, K. and Wolf, A. 2010. *Mapping the Resilience of International River Basins to Future Climate Change-induced Water Variability.* World Bank Water Sector Board Discussion Paper Series 15. Washington DC, The World Bank.

Dourojeanni, A. 2001. *Water Management at the River Basin Level: Challenges in Latin America.* LC/L.1583-P. Santigo, Economic Commission for Latin America and the Caribbean (ECLAC). http://www.eclac.cl/publicaciones/xml/7/7797/Lcl.1583-P-I.pdf

Dourojeanni, A., Jouravlev, A. and Chávez, G. 2002. *Gestión del agua a nivel de cuencas: teoría y práctica.* LC/L.1777-P. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.eclac.cl/drni/publicaciones/xml/5/11195/lcl1777-P-E.pdf

Dinar, A. and Saleth, R. M. 2005. Can water institutions be cured? A water institutions health index. *Water Science and Technology: Water Supply,* Vol. 5, No. 6, pp. 17–40.

Emerton, L. and Bos, E. 2004. *Value: Counting Ecosystems as an Economic Part of Water.* Gland, Switzerland/Cambridge, UK, *International Union for Conservation of Nature* (IUCN).

GWP (Global Water Partnership). 2009. *Institutional Arrangements for IWRM in Eastern Africa.* Policy Brief 1. Stockholm, GWP.

GWP-TAC (Global Water Partnership – Technical Advisory Committee). 2000. *Integrated Water Resources Management.* TAC Background Papers 4. Stockholm, GWP-TAC. http://www.gwpforum.org/gwp/library/TACNO4.pdf

Hamdy, A., Abu-Zeid, M. and Lacirignola, C. 1998. Institutional capacity building for water sector development. *Water International,* Vol. 23, No. 3, pp. 126–33.

Hobbs, P., Oelofse, S. H. H. and Rascher, J. 2008. Management of environmental impacts from coal mining in the Upper Olifants River Catchment as a function of age and scale. M. J. Patrick, J. Rascher and A. R. Turton (eds) *Reflections on Water in South Africa, Special Edition of the International Journal of Water Resource Development,* Vol. 24, No. 3, pp. 417–32.

Hvidtfelt-Nielsen, K. 2010. More than 'mountain guides' of science: a questionnaire survey of professional science communication in Denmark. *Journal of Science Communication,* Vol. 9, No. 2, pp. 1–10.

ICIMOD (International Centre for Integrated Mountain Development). 2009. *Local Responses to Too Much and Too Little Water in the Greater Himalayan Region.* Kathmandu, ICIMOD.

Jønch-Clausen, T. 2004. *'Integrated Water Resources Management (IWRM) and Water Efficiency Plans by 2005' Why, What and How?* Stockholm, GWP.

Jouravlev, A. 2004. *Drinking Water Supply and Sanitation Services on the Threshold of the XXI Century.* LC/L.2169-P. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.eclac.cl/publicaciones/xml/9/19539/lcl2169i.pdf

Junk, W. J., Bayley, P. B. and Sparks, R. E. 1989. The flood pulse concept in river-floodplain systems. D.P. Dodge (ed.) *Proceedings of the International Large Rivers Symposium (LARS), Canadian Special Publication of Fisheries and Aquatic Sciences,* No. 106, pp. 110–27.

Kambatuku, J. R. (ed.) 2003. *FIRM, the Forum for Integrated Resource Management: Putting Communities at the Centre of their own Development Process.* Windhoek, Namibia, Namibia's Programme to Combat Desertification (NAPCOD).

Kaufmann, D. 2005. Myths and realities of governance and corruption. *Global Competitiveness Report 2005–2006.* New York, World Economic Forum (WEF), pp. 81–98.

Klop, P. and Wellington, F. 2008. *Watching Water: A Guide to Evaluating Corporate Risks in a Thirsty World.* New York, JP Morgan Global Equity Research.

Kruger, A. S., Gaseb, N., Klintenberg, P., Seely, M. K. and Werner, W. 2003. Towards community-driven natural resource management. N. Allsopp, A. R. Palmer, S. J. Milton, K. P. Kirkman, G. I. H. Kerley, C. R. Hurt and C. J. Brown (eds) *Namibia: the FIRM Example.* VIIth International Rangelands Congress, Durban, South Africa, pp. 1757–9.

Lannerstad, M. and Molden, D. 2009. *Adaptive Water Resource Management in the South Indian Lower Bhavani Project Command Area.* IWMI Research Report 129. Colombo, International Water Management Institute (IWMI).

Lentini, E. 2009*a*. Regulatory accounting for drinking water and sanitation services. The experience of the Metropolitan Area of Buenos Aires. *Circular of the Network for Cooperation in Integrated Water Resource Management for Sustainable Development in Latin America and the Caribbean,* No. 29. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/drni/noticias/circulares/2/34862/Carta29in.pdf

––––. 2009*b*. Regulatory accounting for drinking water and sanitation services. The experience of the Metropolitan Area of Buenos Aires. *Circular of the Network for Cooperation in Integrated Water Resource Management for Sustainable Development in Latin America and the Caribbean,* No. 30. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/drni/noticias/circulares/1/36321/Carta30in.pdf

Lewis, K., Lenton, R. and Wright, A. 2005. *Health, Dignity, and Development: What Will It Take?* UN Millennium Project. Stockholm/New York, Stockholm International Water Institute (SIWI)/UN Millennium Project, pp. 64–6.

MAWF (Ministry of Agriculture, Water and Forestry). 2010*a*. *Integrated Water Resources Management Plan for Namibia Theme Report 4: The Formulation of Information and Knowledge Systems.* Windhoek, Namibia, MAWF.

––––. 2010*b*. *Integrated Water Resources Management Plan for Namibia – Theme Report 6: Integrated Framework for Institutional Development and Human Resources Capacity Building.* Windhoek, Namibia, MAWF.

Mitchell, T., Ibrahim, M., Harris, K., Hedger, M., Polack, E., Ahmed, A., Hall, N., Hawrylyshyn, K., Nightingale, K., Onyango, M., Adow, M. and Mohammed, S. 2010. *Climate Smart Disaster Risk Management, Strengthening Climate Resilience.* Brighton, UK, Institute of Development Studies (IDS).

Mysiak, J., Henriksen, H. J., Sullivan, C., Bromley, J. and Pahl-Wostl, C. (eds) 2010. *The Adaptive Water Resource Management Handbook.* London, Earthscan.

North, D. 1990. *Institutions, Institutional Change and Economic Performance.* Cambridge, UK, Cambridge University Press.

North, D. C. 1991. Institutions. *Journal of Economic Perspectives,* Vol. 5, No. 1, pp. 97–112.

OECD-DAC GOVNET (Organisation for Economic Co-operation and Development-Development Assistance Committee Network on Governance). 2006. *The Challenge of Capacity Development: Working Towards Good Practice.* Paris, OECD Development Co-operation Directorate (DCD).

Pahl-Wostl, C. 2007. Transition towards adaptive management of water facing climate and global change. *Water Resources Management,* Vol. 21, No. 1, pp. 49–62.

Pahl-Wostl, C., Sendzimir, J., Jeffrey, P., Aerts, J., Berkamp, G. and Cross, K. 2007. Managing change toward adaptive water management through social learning. *Ecology and Society,* Vol. 12, No. 2, Art. 30.

Patterson, K. A. 2009. Case for integrating groundwater and surface water management. D. Michel and A. Pandya (eds) *Climate Change, Hydropolitics, and Transboundary Resources.* Washington DC, Henry L. Stimson Center, pp. 63–72.

Phillips, D., Daoudy, M., McCaffrey, S., Öjendal, J. and Turton, A. R. 2006. *Transboundary Water Cooperation as a Tool for Conflict Prevention and Broader Benefit-Sharing.* Stockholm, Ministry for Foreign Affairs Expert Group on Development Issues (EGDI).

Phillips, D. J. H., Allan, J. A., Claassen, M., Granit, J., Jägerskog, A., Kistin, E., Patrick, M. and Turton, A. R. 2008. *The Transcend-TB3 Project: A Methodology for the Trans-boundary Waters Opportunity Analysis (the TWO Analysis).* Prepared for the Ministry of Foreign Affairs, Sweden. http://www.siwi.org/documents/Resources/Reports/Report23_TWO_Analysis.pdf

Phumpiu, P. and Gustafsson, J. E. 2008. When are partnerships is a viable tool for development? Institutions and partnerships for water and sanitation service in Latin America. *Journal of Water Resources Management,* Vol. 4, No. 3/4, pp. 304–10.

Pres, A. 2008. Capacity building: a possible approach to improved water resources management. *Water Resources Development,* Vol. 24, No. 1, pp. 123–9.

Puckridge, J. T., Sheldon, F., Boulton, A. J. and Walker, K. F. 1993. The flood pulse concept applied to rivers with variable flow regimes. B. R. Davies, J. H. O'Keefe and C. D Snaddon (eds) *A Synthesis of the Ecological Functioning, Conservation and Management of South African River Ecosystems.* Water Research Commission Report No. TT 62/93. Pretoria, South Africa, Water Research Commission (WRC).

Puri, S. and Aureli, A. (eds.) 2009. *Atlas of Transboundary Aquifers – Global Maps, Regional Cooperation and Local Inventories.* Paris, UNESCO-IHP ISARM Programme, UNESCO. [CD only.] http://www.isarm.org/publications/322

Renzetti, S. and Dupont, D. 2003. Ownership and performance of water utilities. *Greener Management International,* Issue 42.

Seely, M., Dirkx, E., Hager, C., Klintenberg, P., Roberts, C. and von Oertzen, D. 2008. Advances in desertification and climate change research: Are they accessible for application to enhance adaptive capacity? *Global and Planetary Change,* Vol. 64, No. 3–4, pp. 236–43.

Seely, M., Klintenberg, P. and Shikongo, S., 2007. Evolutionary process of mainstreaming desertification policy: A Namibian case study. C. King, H. Bigas and Z. Adeel (eds) *Desertification and the International Policy Imperative.* Hamilton, Canada, United Nations University, pp. 107–115.

Snaddon, C. D., Davies, B. R. and Wishart, M. J. 1999. *A Global Overview of Inter-Basin Water Transfer Schemes, with an Appraisal of their Ecological, Socio-Economic and Socio-Political Implications, and Recommendations for their Management.* Water Research Commission (WRC) Report No. TT120/00. Pretoria, South Africa, WRC.

Stakhiv E. Z. and Pietrowsky, R. A. 2009. *Adapting to Climate Change in Water Resources and Water Services.* Perspectives on water and climate change adaptation 15. Co-operative Programme on Water and Climate (CPWC), the International Water Association (IWA), IUCN and the World Water Council (WWC).

Stakhiv E. Z. and Steward, B. 2009. *Needs for Climate Information in Support of Decision-making in the Water Sector.* Draft White Paper. World Climate Conference 3, Geneva.

Tenner, E. 1996. *Why Things Bite Back: Technology and the Revenge of Unintended Consequences.* New York, Knopf.

Timmerman, J. G., Pahl-Wostl, C. and Moltgen, J. (eds) 2007. *The Adaptiveness of IWRM: Analysing European IWRM Research.* London, IWA Publishing.

Timmerman, J. G. and Bernardini, F. 2009. *Adapting to Climate Change in Transboundary Water Management.* Perspectives on water and climate change adaptation 6. Co-operative Programme on Water and Climate (CPWC), the International Water Association (IWA), IUCN and the World Water Council (WWC). http://www.worldwatercouncil.org/fileadmin/wwc/Library/Publications_and_reports/Climate_Change/PersPap_06._Transboundary_Water_Management.pdf

Tropp, H. 2007. Water governance: Trends and needs for new capacity development. *Water Policy,* Vol. 9, No. 2, pp. 19–30.

Turton, A. R. 2007. *Can we Solve Tomorrow's Problems with Yesterday's Experiences and Today's Science?* Des Midgley Memorial Lecture presented at the 13th SANCIAHS Symposium, 6 September 2007, Cape Town, South Africa.

UNDP (United Nations Development Programme). 1997. *Capacity Development.* New York, UNDP.

UNECE (United Nations Economic Commission for Europe). 2009. *Guidance on Water and Adaptation to Climate Change.* Geneva, UNECE. http://www.unece.org/env/water/publications/documents/Guidance_water_climate.pdf

van Scheltinga, C. T., van Bers, C. and Hare, M. 2009. Learning systems for adaptive water management: Experiences with the development of *opencourseware* and training of trainers. M. W. Blokland. G. J. Alaerts and J. M. Kaspersma (eds) *Capacity Development for Improved Water Management.* Delft, The Netherlands, UNESCO-IHE Institute for Water Education, pp. 45–60.

van Stokkom, H. T. C., Smits, A. J. M. and Leuven, R. S. E. W. 2005. Flood Defense in the Netherlands – A New Era, a New Approach. *Water International,* Vol. 30, No. 1, pp. 76–87. http://www.informaworld.com/10.1080/02508060508691839

Velickov, S. 2007. *Knowledge Modelling for the Water Sector: Transparent Management of our Aquatic Environment.* Discussion Draft Paper for the International Symposium 'Water for a Changing World Enhancing Local Knowledge and Capacity', Wednesday, 13 June 2007, UNESCO-IHE Institute for Water Education, Delft, The Netherlands.

Vickers, J. and Yarrow, G. 1988. *Privatization: An Economic Analysis.* Massachusetts Institute of Technology (MIT) Press Series on the Regulation of Economic Activity, No. 18. Massachusetts, The MIT Press.

WCD (World Commission on Dams). 2000. *Dams and Development: A New Framework for Decision-Making.* London, Earthscan.

WHO (World Health Organization)/UN-Water. 2010. *GLAAS 2010: UN-Water Global Annual Assessment of Sanitation and Drinking-Water.* Geneva, WHO.

WHO (World Health Organization)/UNICEF (United Nations Children's Fund). 2010. *Progress on Sanitation and Drinking-Water.* Update. Geneva/New York, WHO/UNICEF.

Winde, F. 2009. *Uranium Pollution of Water Resources in Mined-out and Active Goldfields of South Africa: A Case Study in the Wonderfonteinspruit Catchment on Extent and Sources of U-Contamination and Associated Health Risks.* Paper presented at the International Mine Water Conference, 19–23 October 2009, Pretoria, South Africa.

Winde, F. and Van Der Walt, I. J. 2004. The significance of groundwater-stream interactions and fluctuating stream chemistry on waterborne uranium contamination of streams – a case study from a gold mining site in South Africa. *Journal of Hydrology,* Vol. 287, pp. 178–96.

Wolf, A. T., Natharius, J. A., Danielson, J. J., Ward, B. S. and Pender, J. K. 1999. International river basins of the world. *International Journal of Water Resources Development,* Vol. 15, No. 4, pp. 387–427.

OSU (Oregon State University). n.d. TFDD: Transboundary Freshwater Dispute Database. Corvallis, Oreg., Department of Geosciences, Oregon State University. http://www.transboundarywaters.orst.edu

Wolff, G. and Gleick, P. H. 2002. The soft path for water. P.H. Gleick (ed.) *The World's Water: The Biennial Report on Freshwater Resources, 2002-2003.* Washington DC, Island Press, pp. 1–32.

World Bank. 2010. *Cost Recovery in the Water Sector.* Project Concept Note. Unpublished. Washington DC, The World Bank.

WWAP (World Water Assessment Programme). 2006. *World Water Development Report 2: Water: A Shared Responsibility.* Paris/New York, UNESCO/Berghahn Books.

––––. 2009. *World Water Development Report 3: Water in a Changing World.* Paris/London, UNESCO/Earthscan.

CHAPTER 6

From raw data to informed decisions

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The absence of systematic data collection in most countries impedes regular reporting on water resources and water-use trends. There is consequently a growing interest in and demand for better and more accurate and consistent water data and accounting. This needs to be translated into improved data availability and quality, more structured data acquisition and better information about water. Unfortunately, there has been no major progress since the third edition of the *World Water Development Report* in terms of observation methods, networks and monitoring (see also 'Bridging the observational gap', Chapter 13 in that report).

Global programmes such as WWAP need to focus on core data items from which different users can calculate indicators of specific interest to them. Technological advancements are also making it easier to monitor and report on various dimensions of water resources. The development and application of these new technologies should be made a priority.

6.1 Data, monitoring and the purpose of indicators

The theme of this edition of the *World Water Development Report* (WWDR) is *uncertainty*. This indicates a lack of adequate information on water resources and water-use trends, or that available information is not being used. Regardless of the enterprise in question, whether it is tending a household food garden, managing the business of a multinational food company, or guiding a national economy, successful risk management depends on the availability and collection of sufficient information to properly characterize relevant risks and uncertainties. Risk management for water resources and their uses implies the monitoring of water-related activities to obtain the data necessary to generate the information required by interested parties. Once sufficient data have been amassed, they can be summarized in the form of indicators to address specific areas of concern.

Since it was first published in 2003, the WWDR has included a comprehensive collection of data and indicators about the various dimensions of water resources and their uses. The WWDR has sought to update this information in subsequent editions, and in this fourth edition presents these data and indicators as part of Volume One (Table 6.1).

Table 6.1 presents the indicators that have been developed by WWAP in cooperation with prominent organizations (the members of UN-Water, NGOs, universities, etc). The list is categorized by major challenge areas that are central to the WWDR. Each indicator falls under one or more elements of the DPSIR analytical framework – Driving force, Pressure, State, Impact and Response. The indicator development process is closely linked to WWAP's overarching mandate of monitoring and reporting on water around the world. WWDR indicators are systematically updated and revised to reach the ultimate goal: to develop a set of indicators that are accepted across the entire UN system to monitor performance and track changes, not only in the natural environment (such as the hydrological cycle, the aquatic environment, water quality, and water availability and use) but also in the socio-economic and political environment of the water world (such as in governance, water pricing and valuation).

The goal has been to provide not just snapshots of information, but an indication of how different dimensions of water and its uses are changing over time in different parts of the world. This effort is based on the assumption that better management of limited water resources requires systematic monitoring to determine whether the many and varied public and private policy objectives set for the resource are being achieved. But it also intends to help readers and users of the WWDR to understand better the risks – and the uncertainties – that characterize water resources.

Information about water is becoming increasingly important to the following groups:

- *National governments.* Many countries want reliable and objective information about the state of water resources, their use and management, in order to safeguard their water security as a matter of national survival. In particular, they seek information about trends that may have an impact on them in the future. They often seek to understand their own situation by benchmarking it and making comparisons with other countries and regions.
- *Multilateral organizations.* Several multilateral organizations, such as the OECD, have set policy goals including environmental objectives such as 'decoupling environmental pressures from economic growth' (OECD, 2001, p. 11). The monitoring of parameters such as water-use trends play a key role in achieving such objectives. Many other regional and specialized organizations, ranging from the European Union (EU) and African Union to the G8 have raised related issues.

Water issues are also raised by different sectors at all levels, from local community to global multilateral organizations. Farmers, urban planners, drinking water and wastewater service companies, the disaster management community, business and industry, and environmentalists are all concerned by the current situation:

- The ability to produce sufficient food for growing and increasingly affluent populations is a global concern. Water is an essential resource for food production, therefore, it is important to remain advised of the availability, sustainability and variability of water supplies – whether from rainfall, abstraction from rivers and lakes, or groundwater. The risk that water-related events might affect local food production or prices is an increasingly important political concern.

TABLE 6.1

United Nations *World Water Development Report* indicators

Topic	Indicator	Category in cause–effect approach[a]	Type of indicator[b]
Level of stress on the resource	Index of non-sustainable water use	Driving force, Pressure, State	Key
	Rural and urban population	Pressure, State	Basic
	Relative water stress index	Pressure, State	Key
	Sources of contemporary nitrogen loading	Pressure, State	Key
	Impact of sediment trapping by large dams and reservoirs	Pressure	Key
	Coefficient of variation for the climate moisture index	State	Key
	Water re-use index	Pressure, State	Key
Governance	Access to information, participation and justice	Response	Developing
	Assessing progress towards achieving the integrated water resources management (IWRM) target	Response	Key
Settlements	Percentage of urban population	Pressure, State	Key
	Proportion of urban population living in slums	Pressure, State	Key
State of the resource	Total actual renewable water resources	State	Key
	Total actual renewable water resources per capita	State	Developing
	Inflow from other countries as share of total actual renewable water resources (Dependency Ratio)	State	Developing
	Proportion of total actual renewable freshwater resources withdrawn: MDG Water Indicator	State	Developing
	Groundwater development stress	Pressure, State	Developing
	Brackish/saline groundwater at shallow and intermediate depths	State	Key
Ecosystems	Fragmentation and flow regulation of rivers: dam Intensity	State, Impact	Key
	Dissolved nitrogen (nitrates + nitrogen dioxide)	State	Key
	Trends in catchment protection	State, Response	Key
	Freshwater species population trends index	State	Key
Health	Disability-adjusted life year	Impact	Key
	Prevalence of stunting among children under age 5	Impact	Developing
	Mortality rate of children under age 5	Impact	Developing
	Access to improved drinking water	Impact	Key
	Access to improved sanitation	Impact	Key

Note: An Indicator Profile sheet with a detailed definition and explanation of how the indicator is computed (as well as data tables for some indicators) is available for most indicators at http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/indicators/. Exceptions are sub-indicators for 'Total actual renewable water resources'.

a. The categories are based on the DPSIR (Driving force, Pressure, State, Impact, Response) framework. For details, see WWDR1 (ch. 3, pp. 32–47; http://unesdoc.unesco.org/images/0012/001297/129726e.pdf#page=53) and WWDR2 (ch. 1, pp. 33–38; http://unesdoc.unesco.org/images/0014/001454/145405e.pdf#page=21).

b. Basic indicators provide fundamental information and are well established and widely used; data are generally widely available for all countries. Key indicators are well defined and validated, have global coverage and are linked directly to policy goals. Developing indicators are in a formative stage and may evolve into key indicators following refinement of methodological issues or data development and testing.

Source: Compiled by E. Koncagül, S. Saddhamangala Withanachchi and L. Dubin.

TABLE 6.1

United Nations *World Water Development Report* indicators (continued)

Topic	Indicator	Category in cause–effect approach[a]	Type of indicator[b]
Food, agriculture and rural livelihoods	Percentage of undernourished people	State	Key
	Percentage of poor people living in rural areas	State	Key
	Agriculture GDP as share of total GDP	State	Key
	Irrigated land as a percentage of cultivated land	Pressure, State	Key
	Agriculture water withdrawals as share of total water withdrawals	Pressure	Key
	Extent of land salinized by irrigation	State	Key
	Groundwater use as share of total irrigation	Pressure, State	Key
Industry and energy	Trends in industrial water use	Pressure	Key
	Water use by major sector	State	Key
	Organic pollution emissions (biochemical oxygen demand) by industrial sector	Impact	Key
	Trends in ISO 14001 certification	Response	Key
	Electricity generation by energy source	State	Key
	Total primary energy supply by source	State	Key
	Carbon intensity of electricity generation	Impact	Key
	Volume of desalinated water produced	Response	Key
	Access to electricity	Pressure	Key
	Capability for hydropower generation	State	Key
Risk assessment	Mortality risk index	State	Key
	Risk and policy assessment indicator	Response	Key
	Climate vulnerability index	State	Key
Valuing and charging for the resource	Water sector share in total public spending	Response	Developing
	Ratio of actual to desired level of public investment in drinking water supply	Response	Developing
	Ratio of actual to desired level of public investment in basic sanitation	Response	Developing
	Rate of operation and maintenance cost recovery for water supply and sanitation	Driving force, Response	Developing
	Water and sanitation charges as percentage of various household income groups	Driving force, Response	Developing
Knowledge base and capacity	Knowledge index	State	Developing

Note: An Indicator Profile sheet with a detailed definition and explanation of how the indicator is computed (as well as data tables for some indicators) is available for most indicators at http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/indicators/. Exceptions are sub-indicators for 'Total actual renewable water resources'.

a. The categories are based on the DPSIR (Driving force, Pressure, State, Impact, Response) framework. For details, see WWDR1 (ch. 3, pp. 32–47; http://unesdoc.unesco.org/images/0012/001297/129726e.pdf#page=53) and WWDR2 (ch. 1, pp. 33–38; http://unesdoc.unesco.org/images/0014/001454/145405e.pdf#page=21).

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Source: Compiled by E. Koncagül, S. Saddhamangala Withanachchi and L. Dubin.

"The UN Statistical Division continues to support member countries to develop their physical water accounts so as to better understand where their water comes from and how it is used."

- Similarly, population growth and increasing urbanization raises questions for government planners about the availability of water resources to support such developments and the wastewater impacts they generate. Uncertainty about future pressures on the resource affects water management, but uncertain water availability may itself pose a risk to economic activity and urban development.
- At the community level, existing challenges of ensuring adequate supplies and avoiding undue impacts on water quality as a result of wastewater discharges are being supplemented by threats posed by vulnerability to extreme weather events. These are prompting a review of measures to build resilience to disasters such as floods.
- Water has been identified as a significant future risk to business activities. Many large businesses are seeking to understand better the challenges it poses to their operations, including reputational risk. They are also concerned about the availability of water and the impact of their operations on the quality of the resource. Absence of clear information may influence their investment decisions or even lead to curtailment of operations.
- Environmental stakeholders recognize that water resources are an ecosystem in their own right, as well as being essential to the health of other ecosystems. While both national and international law mandate environmental protection, it is important to monitor the status of aquatic ecosystems in order to assess the effectiveness of such regulation.
- Climate change has helped to focus attention on water-related issues and has raised the levels of uncertainty about parameters such as water availability. These were previously considered as essentially fixed and statistically predictable based on historical records. There is also concern that extreme weather events will occur more frequently. This has highlighted the need to monitor water resource systems more carefully to detect trends as early as possible and support the development of effective responses. As global approaches are developed to respond to this global challenge, it is important to monitor both the impacts on water resource systems of climate change mitigation strategies and the effectiveness of adaptation strategies.

Agreement on broad goals and management strategies, whether direct infrastructural interventions or 'soft policy' adaptive initiatives, is necessary for all these different areas of activity. Once goals and strategies have been defined, their effectiveness needs to be monitored. This requires the definition of appropriate indicators and the generation of adequate data. The key objective is to reduce uncertainty about water resources and their use, thereby supporting the management of risks posed by the complex natural systems of which they form a part.

6.2 Key indicators

A staggeringly extensive array of indicators have been developed, or are proposed, to monitor the state, use and management of water resources, for a wide range of purposes. While the first edition of the WWDR reported on over 160 indicators, only 49 were covered in WWDR4. This reduction occurred, in part, because of the difficulties encountered in obtaining updated data for the indicators, but also reflected consideration about their nature and purpose. As two OECD experts recently commented,

> Indicators are invariably developed to inform and influence different societal, political, technical and institutional processes … a composite indicator developed by an environmental NGO will probably have more success raising awareness among the general public, than as a widely accepted information tool among government analysts. (Scrivens and Iasiello, 2010, p. 9)

Many sector-specific indicators have been proposed and calculated. Aside from simple trends in water use, the water-use efficiency of different sectors in terms of output per unit of water can be a useful indicator. Similarly, monitoring the proportion of treated domestic wastewater can help to understand the impact of water use on the natural environment. But the focus on climate change has also highlighted the importance of selecting appropriate indicators. For example, in South Africa, energy planning requires an informed trade-off between carbon dioxide (CO_2) emissions and water-use efficiency (Box 6.1).

At a broader societal level, there is the widely used concept of national water stress (see Sections 3.1 and 4.6.1), which simply considers the amount of water available to a country per person (Falkenmark et al., 1989). At the other extreme, the water poverty index proposed by Sullivan (2002) seeks to combine a wide range of parameters, including available water resources, water use by three major sectors, four measures of water quality, information about fertilizer and pesticide use, environmental regulatory capacity, the number of EIA guidelines and the percentage of threatened species. Data availability on key issues itself is a formal component of the index.

Since the WWDR3 was published in 2009, a number of important global processes that seek to identify water resource issues and inform water-related policy decisions have gained momentum. One example is the collaborative exercise undertaken by the UN CEO Water Mandate group, including the World Wildlife Fund (WWF). It focused on encouraging its member companies to develop a better understanding of how their operations use water, both in their direct operations and in their supply chains. The Water Footprint Network, a spinoff of research into the virtual water trade between countries, also encourages companies to know and reduce their water use and 'footprint'.[1]

At the national level, FAO's AQUASTAT[2] collects statistics and data on water resources obtained from national sources. These are systematically reviewed to ensure consistency in definitions and between countries sharing the same river basin. A comparative analysis of available country water resources data is also carried out at regular intervals. On this basis, AQUASTAT compiles and updates its best estimates of the main elements of the water balance for each country. For Africa, Asia and Latin America and the Caribbean, AQUASTAT obtains water withdrawal values from ministries or other governmental agencies at country level, although some data gaps are filled using United Nations (UN) data. Eurostat and OECD are valuable sources of information for Europe, Australia, Japan, New Zealand and Northern America, and are also used to fill data gaps.

The Joint Monitoring Programme (JMP)[3] for Water Supply and Sanitation (WHO/UNICEF) is the official UN mechanism tasked with monitoring progress

BOX 6.1

Informing trade-offs: Water for electricity in South Africa

In most countries, economic activity and social stability depend on a sufficient and reliable supply of electrical power. This is explicitly stated in South Africa's National Water Resource Strategy, which regards water use for electricity generation as a matter of strategic importance. However, the strategy specifically states that 'Water use designated as being of strategic importance will be subject to the same efficiency criteria and water demand management requirements as is applied to other uses. Dry cooling of power stations should be applied where feasible when new generating capacity is built.' (DWAF, 2004, p. 52)

Performance measured on the basis of the 'water intensity' of electricity generation, first set as a target in 1970, has been encouraging. Between 1980 and 2006, national power utility ESKOM reported that it had decreased its water use from 2.85 L per kWh to approximately 1.32 L per kWh, largely by the use of dry cooling rather than water cooling for its inland power stations. The water consumption of its newest 4,000 megawatts Matimba Power Station, which claims to be the largest direct-dry-cooled station in the world, is in the order of 0.1 L per kWh (ESKOM, 2009).

Dry cooling carries not just a significant cost penalty but also has climate implications, since the hydrocarbon fuel use and CO_2 emissions of dry-cooled power stations are greater than those of water-cooled ones. However, given South Africa's water stress, this trade-off was considered as acceptable, and the use of a consistent indicator over 40 years has enabled performance to be tracked and sustained. Current electricity planning foresees that the total use of water will actually decline, even as electricity production increases, as more efficient power stations and renewables are brought into the generating mix over the next decade.

towards the Millennium Development Goal relating to drinking water and sanitation (MDG7, Target 7c). The MDG indicators measure access to drinking water and basic sanitation:

- Proportion of population using an improved drinking water source
- Proportion of population using an improved sanitation facility

In fulfilling this mandate, JMP publishes updated estimates every two years on the use of various types of drinking water sources and sanitation facilities at national, regional and global levels. Its success is largely due to the attention paid to generating the base data on which reporting is based.

These approaches all depend on the presence of sufficient, comparable and reliable raw data and processed

BOX 6.2

Australian water accounting standards

Australia is the driest inhabited continent and one of the highest per capita users of water in the world. Communities, irrigators, businesses and environmental groups are constantly debating the equitable distribution of water. Water is a fundamental resource and as competition for it increases, the need to fully and comparably account for how it is managed, maintained and distributed to meet economic, social and environmental needs becomes increasingly important.

In response to these issues, the Council of Australian Governments incorporated a directive into the National Water Initiative (2004) to develop water resource accounting. This would enable water information to be standardized, compared, reconciled and aggregated. In 2006, a stocktaking report recommended the establishment of water accounting as a discipline, similar to financial accounting, to serve external users' needs as well as the management requirements of water businesses.

Australia's approach to water accounting is a systematic process of identifying, recognizing, quantifying, reporting, assuring and publishing information about water, water rights or other claims to water, and obligations against that water. Unlike other types of water resource accounting that currently exist internationally, the development of water accounting in Australia is based on the principles of financial accounting, not statistics, and focuses on the volumes of water rather than their economic value. In addition, the potential audience is far greater due to the scalable size of the entity being reported on.

The role of issuing water accounting standards was given to the Bureau of Meteorology, which created an independent advisory board, the Water Accounting Standards Board, to assist in their development. Between 2007 and 2010, this board – with significant support and assistance from the accounting and hydrology industries – developed and successfully piloted the Water Accounting Conceptual Framework (WACF) and the Exposure Draft of Australian Water Accounting Standard 1 (ED AWAS 1). These documents together provide a principles-based approach to the preparation and presentation of General Purpose Water Accounting Reports (GPWAR).

Water Accounting Reports aim to assist users in making and evaluating decisions about the allocation of water resources by providing a comparable and reliable approach to reporting, while also giving water resource managers an opportunity to demonstrate responsible stewardship of a public good. Furthermore, the production of reports is expected to instil public and investor confidence in how much water there is, who has the rights to it, and how it is being used.

As information about water resources is made more available, better decisions can be made on a broad range of water-related matters. For instance how to:

- Distribute the resource
- Invest in better quantification techniques or infrastructure
- Decide where private enterprise could locate new operations that rely on water
- Cope with an expanding community need when additional water resources are required
- Invest in companies exposed to significant water-related operating risk

While significant progress has been made in the development and adoption of water accounting over a short period of time, the discipline is still in its infancy. In the end, it will be users who determine what information they require to be able to make and evaluate decisions about the allocation of resources.

Note: For more information see www.bom.gov.au/water/wasb information about both water resources and their use. In this area, too, there are encouraging developments. The UN Statistical Division continues to support member countries to develop their physical water accounts so as to better understand where their water comes from and how it is used. Meanwhile, at the national level, Australia – which faces severe pressures from, and difficult choices about, the management of its water resources – is developing sophisticated water accounting systems to support decision-making (Box 6.2).

In 2007, stakeholders of WWAP sought to produce a core group of indicators to address high-level information and policy objectives. In the light of the challenges faced, WWAP, as one of the three operational programmes of the UN-Water consortium, engaged in a systematic review of the different indicators required as well as the data challenges that need to be addressed in order to guide its future work.

In August 2009, a WWAP-led UN-Water Task Force on Indicators, Monitoring and Reporting (IMR) presented its outputs to UN-Water.[4] The Task Force's overarching objective was to contribute to public information and informed decision-making in the water and related sectors, including sanitation, at global and national levels, through improved monitoring and reporting. In particular, it aimed to support international and national decision-makers and advance the implementation of internationally agreed-upon goals and targets on water and sanitation.

This involved the development of a methodology for monitoring, at regular intervals, the state of water resources and their use, as well as the impact of policy and management interventions, including a set of measurable indicators that support both national decision-makers and the international community. A set of fifteen indicators was proposed, with detailed descriptions and methodologies for each one.[5]

While these indicators do not allow for an in-depth analysis of the issues, they serve their intended purpose of informing civil society of critical water issues at the global level. However, the IMR Task Force noted that the development and use of indicators is a dynamic process and that the proposed list is neither final nor exhaustive. Rather, it will evolve as knowledge and data availability improve. A precondition for any robust indicator is collection of accurate, timely and consistent data at country level. Part of this ongoing process will be the provision of technical assistance or tools to facilitate this work.

6.3 State of data and information

The monitoring of water resources and their use represents an immense challenge, especially given the renewable nature and general complexity of water resources, the variability of their distribution in time and space, and the different forms in which they appear. Furthermore, the diversity of monitoring objectives poses additional challenges. In addition, the data required to populate the indicators are seldom systematically or reliably available at global, national, regional or basin level.

The paucity of data is illustrated by Figure 6.1, which summarizes data availability in the countries of the Southern African Development Community (SADC).

A particular challenge is maintaining a regular flow of comparable data that can be used to monitor trends in different parameters over time. While data gaps have often been patched by the use of models, the quality of the information then becomes dependent on having sufficient field data to calibrate and 'ground truth' the model.

A WWAP Expert Group on IMR considered the availability of data and the actions that could be taken to enhance data flow. One finding was the existence of a limited set of key 'data items' needed to calculate a wide range of different indicators. For example, one key data item needed to calculate the values of many national level indicators is the Total Actual Renewable Water Resource (TARWR), whether at the basin, state, national or regional level. In the past, the TARWR has

> "Without actual use data, improvements in water productivity cannot be tracked, even if they are substantial."

been calculated on the basis of information collected over a 30-year period (the 1960–1990 period was a widely used benchmark). Important indicators, such as water scarcity (TARWR per capita) and water productivity (GDP per TARWR) are based on these measures.

However, the TARWR has not been routinely monitored and no methodology exists for its systematic updating. So, while indicators such as national water scarcity have changed over the past decade, these changes have usually simply reflected changes in underlying populations. Changes in water availability have not been systematically recorded and are not generally reflected in global water scarcity data. The general assumption was that hydrology is 'stationary' (see Chapters 5, 8 and 11).

However, concerns about climate change, one of the factors that have led to the growing interest in water indicators, have resulted in explicit recognition that the 'stationary hydrology' assumption can no longer be used as the basis for high-level reviews of water availability. This has focused attention on the limited availability of global data on stream flows, on which estimates of water resource availability need to be based. While there are a great deal of available data on precipitation, which can be measured by remote sensing, changes in runoff to rivers or recharge of groundwater are much harder to measure. In general, data availability is particularly poor for groundwater and water quality.

Water-use data are often even more difficult to obtain than data on the state of the resources themselves. As an example, data are needed to assess the productivity of water, in terms of GDP per unit of water used, to enable monitoring of the policy objective of decoupling economic activity from resource use. Similarly, the efficiency of water use in different industrial processes

FIGURE 6.1

Dashboard of data availability in SADC countries

	Surface and groundwater	Infra-structure	Water supply sources and returns to environment	Water uses and allocation	Wastewater	Water efficiency	Water charges (tariffs, taxes, subsidles)	GDP	Water financing and production costs
Angola	Substantial information	No response received	No response received	Some but limited information	No response received	No response received	Some but limited information	Substantial information	No response received
Botswana	Substantial information	Some but limited information	Some but limited information	Substantial information	Substantial information	Substantial information	Substantial information	Substantial information	Substantial information
Democratic Republic of the Congo	Substantial information	Little information	Little information	Some but limited information	No response received	Little information	Some but limited information	Substantial information	Little information
Southern	Substantial information	Some but limited information	Some but limited information	Some but limited information	Little information	Little information	Some but limited information	Substantial information	Little information
Madagascar	Substantial information	Some but limited information	Some but limited information	Some but limited information	No response received	No response received	Some but limited information	Substantial information	Little information
Malawi	Substantial information	Little information	Some but limited information	Little information	No response received	No response received	Some but limited information	Substantial information	Little information
Mauritius	Substantial information	Little information	Some but limited information	Little information	Some but limited information	Substantial information	Substantial information	Substantial information	Little information
Mozambique	Substantial information	Some but limited information	Little information	Substantial information	Little information	Little information	Substantial information	Substantial information	Some but limited information
Namibia	Substantial information	Little information	Some but limited information	Substantial information	Little information	Substantial information	Substantial information	Substantial information	Some but limited information
Seychelles	Substantial information	Little information	Some but limited information	Substantial information	Little information	Some but limited information	Substantial information	Substantial information	Some but limited information
South Africa	Substantial information	No response received	Some but limited information	Substantial information	No response received	No response received	Substantial information	Substantial information	Little information
Swasiland	Substantial information	No response received	Some but limited information	Substantial information	Little information	Little information	Substantial information	Substantial information	Some but limited information
United Republic of Tanzania	Substantial information	Little information	Some but limited information	Some but limited information	No response received	Some but limited information	Substantial information	Substantial information	Little information
Zambia	Substantial information	Some but limited information	Some but limited information	Some but limited information	Little information	Little information	Substantial information	Substantial information	Some but limited information
Zimbabwe	Substantial information	Little information	Some but limited information	Some but limited information	No response received	No response received	Substantial information	Substantial information	Little information

Little information · Substantial information · Some but limited information · No response received

Source: SADC (2010, table 4, p. vii).

may usefully be monitored to determine the efficacy of water demand management programmes. In practice, however, water use is often estimated using standard assumptions of water consumption in specific industries. Without actual use data, improvements in water productivity cannot be tracked, even if they are substantial. The impacts of technological progress may thus be missed unless detailed surveys are carried out into water use by specific sector. Similarly, the lack of knowledge about water use in many sectors means that opportunities and priorities to promote more efficient use of water may not be identified.

These examples highlight the need for greater focus on data generation to enable water managers to monitor the trends of most concern to policy-makers.

6.4 Constraints on better monitoring and reporting

6.4.1 Institutional and political constraints

Many institutional and political constraints inhibit better monitoring and reporting of information on water resources and their use. Good management generates good data; poor management is frequently a consequence of poor data, while also contributing to the broader data gap.

Because of the relatively low value and wide distribution of water, its use, particularly in irrigation, is usually not measured directly. From an operational perspective, it is usually more important in conditions of scarcity to decide on the priorities and proportionate shares for available water, rather than to measure exact quantities. In many jurisdictions, water allocations are made at different levels of reliability for different classes of user to avoid detailed quantitative measurements.

Furthermore, because the production of water is a natural rather than a man-made process, there is little certainty in most situations about the initial supply. This distinguishes it from other utility operations and natural resource contexts. For example, in energy production the quantity of coal delivered from a mine to a power station is known; similarly, the amount of electricity that flows from the power station is measured by the generating company whose survival depends on measuring and billing its customers for the energy supplied. With water resources, however, there is no coal-burning or any other routine measurement of the amount of water that flows into the system.

In addition, because water resources are often shared between a number of different political jurisdictions, there is often a disincentive for upstream communities to share information about resource availability and use with downstream jurisdictions, as the information may be used in disputes about the division of the resource. It is also common for private companies to withhold and avoid disclosure of information on water availability and use, alleging that these data are of strategic importance for their business activities.

This phenomenon is best known in river basins shared between countries (as with large basins such as the Ganges and the Mekong); however, similar logic may also apply in countries with federal systems of government in which water resource management lies in the

BOX 6.3

Water resource information for conflict prevention in Central Asia

The dissolution of the Soviet Union in 1989 created a number of difficult water resource management challenges for the countries that emerged. Beforehand, the central government had taken decisions about the use and sharing of water between regions; afterwards, such decisions became the province of sovereign countries, which have different criteria. As a result, the potential exists for conflict between them. This in turn has been identified as a potential risk, and one that could aggravate existing conflicts in neighbouring countries. One simple response to this, identified by the United States of America, proposes the provision of better water resource information as the first essential step:

> Provide benchmark data to improve water management
>
> The countries in Central and South Asia, regardless of their level of development, lack publicly available access to consistent and comparable data on water supply, flow and usage. This creates tension over the management of water by both upstream and downstream countries. Providing basic technical information to all countries is a constructive way for the United States to help create a foundation for bona fide discussion and debate over water management. The United States should support data-related activities specific to measuring and monitoring water flow and volume for key rivers and river basins. We should also promote technical partnerships in the region to monitor glaciers, track shifts in monsoons, and model climatic changes across a range of water flow scenarios. (US Senate, 2011, p. 2)

hands of provincial or state administrations, which may have similar motivations. The corollary is that where a potential for conflict exists between neighbours, addressing the data challenge may constitute an important mechanism to manage disputes (Box 6.3).

6.4.2 Definitional issues: Performance measurement challenges

A further constraint on improved monitoring and reporting is the lack of agreement on what should actually be monitored. For example, the establishment of performance targets with effective measures is essential to achieving policy goals such as sustainable development and the MDGs, but there is often uncertainty about what data items will best serve this purpose.

It is necessary to address the potential impacts of decisions needed within a cost–benefit analysis. Criteria will be needed to guide the selection of measures. These will include considerations such as the value of ecosystem services that make optimization more complex, but also potentially more effective. Decision-support systems are needed that combine classical cost–benefit with participatory multi-criteria analyses, addressing different levels of uncertainties.

To achieve a balanced allocation and the protection of water resources, indicators should support carefully designed and selected policy instruments. They may include regulations (technical standards, performance standards, etc.), quotas, access rules and allocation procedures, as well as economic instruments (especially pricing mechanisms and payments for ecosystem services).

While economic theory suggests that pricing policies may be useful for achieving targets, in practice, prices serve several conflicting purposes: financing of water service-related infrastructure, incentives for efficient use of scarce resources, and fairness and distributional justice (see Chapter 10). Simply monitoring water prices does not necessarily provide a useful indication of policy success, unless it is done in a manner that reflects the real-life objectives of improved water management.

6.4.3 Technical and financial constraints

In addition to the political and institutional barriers to the generation and reporting of water resource availability and use information, there are also substantial technical and financial constraints.

Because water occurs in natural structures whose behaviour often varies from one season to the next, measuring simple parameters such as flow can be extremely expensive. The cost of a single river gauging station for a medium-size river can easily exceed US$1 million, and the costs of ongoing operation, maintenance and reporting can be difficult to justify in poor countries where such activities compete with basic water supply for limited funds, yet bring no immediate benefits.

One important yet underused resource is remote sensing. As yet, it has not resulted in a significant flow of useful processed information about water and its use. While the direct use of water by field crops can now be reliably assessed using remotely accessed data, it is more difficult to determine the amount of water actually abstracted from rivers and dams to irrigate the fields. This is because it is not yet possible to determine parameters such as the flow of water in rivers from remotely sensed information. This means that a critical indicator cannot be assessed: the efficiency with which abstracted water is delivered to the fields and actually used for crop production.

It is also possible to remotely monitor water quality-related parameters, which would assist management challenges such as eutrophication and the protection of natural ecosystems such as wetlands on a systematic basis. Existing remote-sensing technologies have a number of important applications; however, the relatively low priority accorded to water resource monitoring means that these are not applied.

While remote sensing is proving to be a useful tool, it will never substitute the need to gather local information. Using remote sensing data without ground truth may be risky and it would be ill-advised to suggest that governments not spend on hydromet networks in favour of remote sensing data. Remote sensing and hydromet measuring networks are not mutually exclusive, and strengthening hydromet networks and services is a necessary condition for proper water resources management, planning, design and operation.

6.5 Improving the flow of data and information

6.5.1 The emerging market for better data and indicators

While WWAP's mandate is to collate and report available information on the state of water resources and their use at a global level, it has become apparent that data constraints are limiting the programme's ability to do this, specifically in relation to the systematic monitoring of important trends. In order to carry out its mandate effectively, it must therefore identify the data requirements to enable the tracking of key policy goals and emerging changes, and to support efforts to implement monitoring systems that can generate the data required.

The most effective driver of efforts to improve the flow of information about water would be demands for information on the part of policy-makers and decision-makers in the socio-economic sectors of activity. There are, however, encouraging signs that more attention is being paid to the need to generate better data flows to support the monitoring of water resources and their use.

From a government perspective, economic policy-makers now recognize that water as a resource has an important influence on national economies, which is largely unaccounted for. As a result, there is a growing interest in water accounting in parallel with broader environmental accounting. The initiatives of the UN System of Environmental-Economic Accounting for Water (SEEAW) and Eurostat are particularly significant in this regard, as are the recent efforts of OECD.

The importance of water resource data for national and regional security is demonstrated by the example from Central Asia, cited above. And as the business sector turns its attention to managing the risks posed by water, it has found that the 'data drought' (IBM, 2009, p. 10) adds to existing uncertainties.

An important initiative from the perspective of business is the UN Global Compact CEO Water Mandate. Established in 2007, it recognized that emerging crises in water services and water resources posed a range of risks to the private sector – as well as opportunities. It also recognized that current water management practices are inadequate given the increasing materiality and importance of water as a resource. Mandate members acknowledge that, in order to operate in a more sustainable manner, they have a responsibility to make water resources management a priority, and to work with governments, UN agencies, NGOs and other stakeholders to address this global water challenge. They have also turned their attention to the challenge of data availability. Linked to this, business leaders at the World Economic Forum in 2009 issued a call to action to raise awareness about water challenges.

"From a government perspective, economic policy-makers now recognize that water as a resource has an important influence on national economies, which is largely unaccounted for."

Specifically, they pledged action to work on unifying water data collection, management and disclosure approaches for business (Box 6.4).

There are many other initiatives underway. The World Business Council on Sustainable Development (WBCSD) has produced a 'water tool' to help business to monitor its use of and impact on water more systematically. The Water Footprint Network similarly encourages businesses, their customers and other stakeholders to become more aware of the water content of their products and operations (Hoekstra et al., 2011).

There is implicit competition between these different approaches, with one focusing specifically on corporate water use while others seek to engage and understand the resource in its catchment context: 'beyond the factory fence'. However, both approaches to monitoring and evaluating the state of water resources and their use are effective in that they depend on the availability of sufficient data to draw well-substantiated conclusions.

The interest from governments and corporate water users is also beginning to be complemented by an interest from the broader public. Civil society organizations such as the World Resources Institute have included access to information about water resources in their overall programme to promote greater public access to environmental information – a programme that has traditionally focused on more contentious natural resources such as minerals, land and forests.[6]

It would thus appear that, after many decades of decline, the market for water-related data may be growing and becoming demand-driven rather than supply-driven. This suggests that there are now significant opportunities for the global community of water practitioners, as well as water users and the much broader community that has a stake in water, to make substantial improvements in the availability and quality of information about the resource. Moreover, the new focus on monitoring water resources is helping to raise awareness among a broader community about the current limitations of available information.

6.5.2 Technological opportunity and data innovation

Technology is also making a contribution. One example is the development of techniques that enable evapotranspiration from crops to be measured directly at a variety of scales, including by remote sensing (Hellegers et al., 2009). New partnerships may also play a role; for example, data about signal attenuation between mobile phone towers can help to make accurate estimates of precipitation, which means that telecommunications service providers can help to fill data gaps. Another potentially more significant development is the deployment of the GRACE family of satellites, which have enabled the application of remote gravimetric measurement to determine changes in the total water stock in specific geographical areas. Although still only experimental and working at a large scale, this technology has already demonstrated the potential to monitor changing groundwater reserves in large alluvial basins. This is of substantial policy interest given the dangers of depletion that these resources face.

One pilot initiative of WWAP is a collaboration to produce a dynamic estimate of the basic data item, the TARWR (Total Actual Renewable Water Resources). The

BOX 6.4

Data as a gateway to progress for sustainable water management

At the 2009 World Economic Forum (WEF), data and information was identified as a key area requiring more attention. Why is the issue important?

Water security and pollution in water-stressed countries is a growing concern for many companies, especially in the power, mining, food and beverage, and semi-conductor sectors. The last few years have seen a plethora of reports from business associations, financial analysts and companies on the strategic importance of water security. The UN Global Compact CEO Water Mandate is a good example of this emerging trend.

Companies will increasingly be asked to provide details of their water-related risks to investors and their water-use efficiency measures to the public. They will also be attracted to countries with sound water management policies. Water security risks are difficult for businesses and investors to assess, due both to poor information about underlying supply conditions and inadequate and irregular reporting and disclosure practices by individual companies (Levinson et al., 2008).

> Quantitative indicators make it possible to spot problems, track trends, identify leaders and laggards, and highlight best management practices ... What is shocking is how little water data is available on a methodologically consistent basis across countries. Much of the existing water data has been collected without regard to cross-country comparisons. (Daniel C. Esty, Director, Yale Center for Environmental Law and Policy, US, cited in WEF, 2009, p. 12)

There is also a need for better data at country level. A participative session on India concluded that one of the obstacles to implementing potential solutions to the country's water problems was the lack of understanding and awareness of the issue:

> Participants strongly agreed that water security is already a critical issue for India as the problem becomes more visible, but the sense of urgency has yet to percolate through to the general public and political leaders. Better quality of data and data transparency through an independent authority or group may help provide further insight into the situation....
>
> Data, Transparency and Analytics: The impact of the water problem will need to be quantified by different stakeholders so that they can understand the extent of the problem. Additional analytics need to be produced by independent actors that will help or pressure governments and other stakeholders into action (such as additional water metrics/index/benchmarking tools/water footprint). (WEF, 2009, p. 52)

TARWR is used as a variable in many key indicators, but is currently only available on a static basis, largely based on estimates of river flows for the period 1960–1990. The key innovation is to base the estimate of available water on a combination of observed hydro-meteorological and surface elevation data and to produce long-term moving averages. This approach will move away from the constraints of 'stationary hydrology' and permit the identification of trends in TARWR. Although the approach still has to be further developed, its observational basis and dynamic nature strongly indicate that it could become the primary point of reference for national water availability (Box 6.5).

As mentioned in Section 6.4.3, there are a number of other areas in which remote sensing may be harnessed to improve the quality of information about critical water resource parameters, notably water quality and environmental protection. Further work in these areas could also produce methodologies to enable the systematic monitoring of global trends in, for example, eutrophication of water bodies and changes in wetland extent. However, as mentioned earlier, using remote sensing data without ground truth may be risky and will never be a substitute for gathering local information.

BOX 6.5

WWAP's dynamic TARWR pilot initiative with CUNY and GWSP

WWAP's pilot initiative is a collaboration with the City University of New York (CUNY) and the Global Water System Project (GWSP) to produce a dynamic estimate of the basic data item, the TARWR (Total Actual Renewable Water Resources). TARWR is the fundamental measure of water resource availability (in a country, river basin or region) and is used in many indicators. It is defined as the maximum theoretical amount of water actually available for the country (or other unit), calculated from:

- Sources of water within a country itself
- Water flowing into a country
- Water flowing out of a country (treaty commitments)
- Availability, defined as the surface and groundwater resource volume renewed each year in each country, means the amount of water theoretically available for use on a sustainable basis. In more specific terms, TARWR is the sum of:

External water resources entering the country
  - Surface water runoff (SWAR) volumes generated in the country
  - Groundwater recharge (GAR) taking place in the country

Less:
  - The volume in the country of the total resource effectively shared as it interacts and flows through both the groundwater and surface water systems; not to subtract this volume would result in its being counted twice (it is also referred to as 'overlap').
  - The volume that flows to downstream countries based on formal or informal agreements or treaties

The WWAP Pilot Study on Indicators (PSI) is being undertaken at the CUNY by Charles Vörösmarty in partnership with the Global Terrestrial Network for Hydrology (GTN-H) and GEO/IGWCO (Water Community of Practice), with support from the US Army Corps of Engineers (USACE). The group has developed an innovative methodology for estimating country-level TARWR. This approach is based on (but not limited to) a combination of hydro-meteorological and high-resolution (6 minute river network and ESRI country boundaries) surface elevation data, which will allow the identification of TARWR trends (e.g. if certain countries are getting wetter or dryer) and variability (e.g. variation of water supply from one year to the next).

This 'dynamic TARWR' is used to produce an alternative set of countries' per capita water availability. This data item will be further developed. Given its observational basis and dynamic nature, it is hoped that it will eventually become the primary point of reference, as it enables longer-term variations in water availability to be tracked over time. This will overcome some of the current constraints imposed by the assumption of stationary hydrology, which is considered to be inappropriate in the face of climate and related challenges

The present TARWR series is produced by the Food and Agriculture Organization of the United Nations (FAO)'s AQUASTAT programme (TARWR-FAO, 2003). It is computed on the basis of available country water resources data sheets and country water balance computational spreadsheets. FAO refers to the data as the 'Best Estimate' and updates the data when further information is provided.

6.5.3 Institutional responsibilities, constraints and opportunities

While many organizations collaborate to produce water resource information, for many of them water is not their primary focus. This can pose certain challenges. The three key water resource agencies in the UN system are UNESCO, FAO and the World Meteorological Organization (WMO), while the United Nations Environment Programme (UNEP) also has a growing interest in water resources and water quality through its Global Environment Monitoring System (GEMS) Water Programme. WMO addresses basic hydrological data through its science platform and the Global Runoff Data Centre (a repository for the world's river discharge data), while the FAO's AQUASTAT programme provides a platform for data on water resources and their use, which has progressed substantially beyond the agricultural domain. However, all three organizations already have substantial general mandates: FAO has global oversight of food and agriculture, UNESCO has a broad responsibility to support science, culture and education, and WMO's global remit is primarily to monitor the atmospheric dimensions of weather and climate. While water resources may not constitute a top priority for these organizations, they all maintain substantial water programmes, an example of which is FAO's recent announcement of the establishment of a 'water platform' to coordinate water-related activities across the organization. Other examples include WMO's Hydrology and Water Resources Programme and UNESCO's science-education-assessment 'suite' comprising its International Hydrological Programme (IHP), the IHE Institute for Water Education and WWAP, in addition to a network of regional hydrologists. As the coordination mechanism across the UN system, UN-Water can play a key role in linking these various programmes, and members of the aforementioned UN-Water Task Force on Indicators, Monitoring and Reporting has begun work on a Federated Water Monitoring System and Key Water Indicators Portal.

A further challenge is that the surface flow component of the water cycle is largely local in character. As such, it receives relatively little systematic attention from the scientific community, which is engaged in global earth observations. Thus, relatively few of the many programmes that together constitute the Global Climate Observation System address water on a broad as opposed to a local basis. One exception is the Global Water Systems Project (GWSP), although its resources are significantly smaller than those available for other dimensions of weather and climate.

However, these global approaches are complemented, if not fed in terms of data, by national level approaches, supported by emerging efforts to promote national water accounting. These too reflect different approaches. For example, while the UN System of Environmental-Economic Accounting for Water (SEEAW)'s model system seeks to address quantity (and to a lesser extent, quality), a financially based approach is being taken to water accounting in Australia, although this faces significant challenges to manage the impacts of dramatic variability on the national economy and society. As already indicated, similar diversity is apparent in the efforts of the business community focusing either on the specific water footprint of individual business enterprises or the broader dynamics of water resources and their use 'beyond the factory fence'. This diversity of approaches could be seen to reflect confusion. However, it should be understood as an important and encouraging indicator of the renewed global interest in the state of water resources, their management and use.

Notes

1 A review of the different approaches and their implications is contained in Muller (forthcoming 2012).

2 See http://www.fao.org/nr/water/aquastat/main/index.stm

3 For more information see http://www.wssinfo.org/about-the-jmp/introduction/

4 For more information see http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/indicators/un-water-tf-on-imr/

5 For more information see http://www.unwater.org/indicators.html

6 For more information see http://www.accessinitiative.org/tai-global-meeting-2008/node/1

References

DWAF (Department of Water Affairs and Forestry). 2004. *National Water Resource Strategy* (1st edn), Pretoria, South Africa, DWAF.

ESKOM. 2009. *Reduction in Water Consumption.* Sandton, South Africa, ESKOM. http://www.eskom.co.za/c/article/240/water-management/ (Accessed 20 October 2011).

Falkenmark, M., Lundqvist, J. and Widstrand, C. 1989. Macro-scale water scarcity requires micro-scale approaches. *Natural Resources Forum,* Vol. 13, No. 4, pp. 258–67.

Hellegers, P. J. G. J., Soppe, R., Perry, C. J. and Bastiaanssen, W. G. M. 2009. Remote sensing and economic indicators for supporting water resources management decisions. *Water Resource Management,* 24 December.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. and Mekonnen, M. M. 2011. *The Water Footprint Assessment Manual: Setting the Global Standard.* London, Earthscan.

IBM. 2009. *Water: A Global Innovation Outlook Report.* Armonk, NY, IBM Corporation. http://www.ibm.com/ibm/.../ibm_gio_water_report.pdf

Levinson, M., Lee, E., Chung, J., Huttner, M., Danely, C., McKnight, C. and Langlois, A. with Klop, P. and Wellington, F. 2008. *Watching Water: A Guide to Evaluating Corporate Risks in a Thirsty World.* New York, JP Morgan Securities Inc.

Muller, M. (forthcoming 2012). Water accounting, corporate sustainability and the public interest. J. M. Godfrey and K. Chalmers (eds) *International Water Accounting: Effective Management of a Scarce Resource.* London, Edward Elgar.

OECD (Organisation for Economic Co-operation and Development). 2001. *Environmental Strategy for the First Decade of the 21st Century.* Paris, OECD.

SADC (South African Development Community). 2010. *Economic Accounting of Water Use Project: Baseline Study Report* ACP-EU Water Facility, Grant No. 9ACP RPR 39–90. SADC.

Scrivens, K. and Iasiello, B. 2010. *Indicators of 'Societal Progress': Lessons from International Experiences.* OECD Statistics Working Papers, 2010/4. Paris, Organisation for Economic Co-operation and Development (OECD) Publishing. doi: 10.1787/5km4k7mq49jg-en.

Sullivan, C. 2002. Calculating a water poverty index. *World Development,* Vol. 30, pp. 1195–210.

TARWR-FAO (Total Actual Renewable Water Resource – Food and Agriculture Organization of the United Nations). 2003. *Review Of World Water Resources By Country.* Water Reports 23. Rome, FAO. http://www.fao.org/DOCREP/005/Y4473E/Y4473E00.HTM

US Senate. 2011. *Avoiding Water Wars: Water Scarcity and Central Asia's Growing Importance for Stability in Afghanistan and Pakistan.* A majority staff report prepared for the use of the Committee on Foreign Relations, United States Senate, 112th Congress, first session 22 February 2011.

WEF (World Economic Forum). 2009. *World Economic Forum Water Initiative. Managing Our Future Water Needs for Agriculture, Industry, Human Health and the Environment.* Draft for Discussion at the World Economic Forum Annual Meeting, Davos, January 2009. https://members.weforum.org/pdf/water/WaterInitiativeFutureWaterNeeds.pdf

CHAPTER 7

Regional challenges, global impacts

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For the first time in the *World Water Development Report* series, this fourth edition reports at a regional level on the status of water resources, their uses and management through the introduction of five regional reports (in Part 3/Volume 2) and their respective summaries in this chapter. The regional reports cover:

- Europe and North America
- Asia and the Pacific
- Latin America and the Caribbean
- Africa
- Arab and Western Asia region

The delineation of the five regions follows the regional division of the United Nations regional economic commissions (UNECE, UNECA, UNESCWA, UNECLAC and UNESCAP; maps of the Member States are provided in the corresponding sections of this chapter), with the exception of the reports on Africa and the Arab and Western Asia region. For these two reports, it was decided (in agreement with UNECA and UNESCWA) that all the Arab countries would be reported on in a broad Arab and Western Asia report, rather than having some of them included in the Africa report and others in the Western Asia report. Each regional report was prepared by the corresponding regional economic commission, with the exception of the Africa report, which was prepared by WWAP in consultation with UN Water/Africa, the African Ministers' Council on Water (AMCOW) and UNECA.

The regional reports highlight the main issues the regions are facing today, and how they have been changing over recent years. Each report lists the most important external drivers for the region, analyzing the resulting pressures and effects the drivers have on water resources, their uses and management. In line with the main theme of the WWDR4, the principal risks and uncertainties and opportunities related to the regions are reported, as well as geographic hotspots and sectoral issues of particular concern. Findings are supported by specific examples. Response options are provided to help the decision-makers identify solutions to their specific issues.

In this chapter a summary of each of the regional reports (Chapters 29 to 33) is provided. The chapter closes with an examination of the inter-linkages between different regions and global challenges, which describes how actions in one part of the world can create negative impacts, as well as opportunities, in others.

7.1 Africa

Map 7.1 shows the UNECA member countries; however, for the purposes of this chapter, the Africa region comprises 46 countries and excludes the northernmost countries of Algeria, Djibouti, Egypt, Libya, Mauritania, Morocco, Sudan, South Sudan and Tunisia, which are covered in Section 7.5, 'Arab and Western Asia Region'. In other words, the Africa region here more or less corresponds to the political definition of sub-Saharan Africa. This region has a total area of 24 million km^2,

MAP 7.1

UNECA Member States

Source: Economic Commission of Africa, Map No. 3975 Rev.8, November 2011. Department of Field Support, Cartographic Section, United Nations.
Note: The region is divided into subregions as follows.
Northern: *Algeria, Egypt, Libya, Morocco, Tunisia.*
Sudano-Sahelian: *Burkina Faso, Cape Verde, Chad, Djibouti, Eritrea, Gambia, Mali, Mauritania, Niger, Senegal, Somalia, South Sudan, Sudan.*
Gulf of Guinea: *Benin, Côte d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone, Togo.*
Central: *Angola, Cameroon, Central African Republic, Congo, Democratic Republic of the Congo, Equitorial Guinea, Gabon, Sao Tome and Principe.*
Eastern: *Burundi, Ethiopia, Kenya, Rwanda, Uganda, United Republic of Tanzania.*
Southern: *Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe.*
Indian Ocean Islands: *Comoros, Madagascar, Mauritius, Seychelles.*

which represents about 18% of the world's landmass (FAO, 2008). Africa's climate is influenced by the equator, the two tropics and its two major deserts: the Sahara in the northern hemisphere and the Kalahari in the southern hemisphere. Rainfall distribution is extremely uneven, both spatially and temporally, which has major implications for livelihoods and human well-being on the continent (FAO, 2005).

Water's crucial role in accomplishing the continent's development goals is widely recognized. Africa faces endemic poverty, food insecurity and pervasive underdevelopment, with almost all countries lacking the human, economic and institutional capacities to effectively develop and manage their water resources sustainably. Sub-Saharan Africa uses barely 5% of its annual renewable freshwater. Yet access to improved water supplies, in both urban and rural contexts, is still the lowest in the world. Most countries do not take full advantage of available arable lands for agricultural production and irrigation expansion, and hydroelectricity is underdeveloped in most places. The Economic Commission for Africa notes that the key issues in Africa are 'investing in the development of Africa's potential water resources, reducing drastically the number of people without access to safe water and adequate sanitation, ensuring food security by expanding irrigation areas and protecting the gains of economic development by effectively managing droughts, floods and desertification' (NEPAD, 2006, 2).

Africa Water Vision 2025 has been adopted by African governments, the New Partnership for Africa's Development and the African Union. This is evidence of a new focus on water and, potentially, better-targeted investment and more efficient water management. Africa Water Vision 2025 calls for enhanced institutional frameworks for the strategic adoption of the principles of integrated water resources management (IWRM). Most African countries have adopted IWRM as the basis for water governance and management. International water policy recommendations continue to play an invaluable and decisive role.

7.1.1 The driving forces and pressures on water resources

High population growth, poverty and underdevelopment are key drivers affecting how water is managed in the region. The development of drinking water and sanitation programmes and other water sector activities in Africa need to take into account the prevailing demographic, economic, political and climatic environments and their impact on water resources and water demands.

Demographics

Africa's rising population is driving demand for water and accelerating the degradation of water resources in many countries. By mid-2011, Africa's population (again excluding the northernmost states) was about 838 million and its average natural rate of increase was 2.6% per annum, compared to the world average of 1.2%. According to one estimate, its population will grow to 1,245 million by 2025 and to 2,069 million by 2050 (PRB, 2011).

An estimated 61% of Africans live in rural areas, exceeding the world average of 50%, and the average population density is 29 people per square kilometre. Urban population grew at 3.4% between 2005 and 2010, which is 1.1% faster than the rural population growth rate (UNEP, 2010*b*). The urban slum population in sub-Saharan African countries is expected to double to around 400 million by 2020, if governments do not take immediate and radical action (UN-Habitat, 2005). However, since remaining flexible is a survival strategy, urban slum populations are highly mobile and numbers are difficult to assess. It is clear, though, that improvements are not keeping pace with the rapid growth of sub-Saharan slum populations (UN-Habitat, 2010). This rapid and poorly managed growth of urban areas, especially in peri-urban slums, has overwhelmed most municipal water services and constitutes a major challenge to water and sanitation development.

On the other hand, population growth is stabilizing: there has been a progressive reduction in the growth rate from about 2.8% in 1990–1995 to a projected value of about 2.3% in 2010–2015 (FAO, 2005). This trend, coupled with increasing economic growth, is likely to contribute to increased socio-economic development, including better water management and the provision of water-related services.

Economic development and poverty

Sub-Saharan Africa is the world's poorest and least-developed region, with half its population living on less than a dollar a day. About two-thirds of its countries rank among the lowest in the Human Development Index (FAO, 2008). Even when opportunities exist to address outstanding water issues, deep and widespread poverty across the African region constrains the ability of many cities and communities to provide proper water and sanitation services, sufficient water for economic activities and to prevent water quality from deteriorating (UNEP, 2010*b*).

Far-reaching economic reforms adopted across the continent have begun to yield positive results in many countries. Negative trends in gross domestic product (GDP) have given way to progressively increasing growth, averaging around the mean figure for developing countries. Analysis by the Economist reveals that in the ten years up to 2010, six of the world's ten fastest-growing economies were in sub-Saharan Africa (*The Economist*, 2011). Nevertheless, average per capita GDP growth in Africa remains far below all other regions.

The economies of most African countries depend largely on rainfed agriculture as the major driver of economic growth. It represents about 20% of the region's GDP, 60% of its workforce, 20% of its export goods, and 90% of rural incomes. Agriculture is by far the largest user of water, accounting for about 87% of total water withdrawals (FAO, 2008). Investing in agriculture, and especially in irrigated farming, is at least four times as effective at raising poor people's incomes as is investment in other sectors (UNEP, 2010*b*).

7.1.2 Challenges, risks and uncertainties

Hydrological variability

Africa's climate is characterized by extremes, from a humid equatorial climate at the equator, through tropical and semi-arid in the middle of the region, to an arid climate towards the northern and southern fringes. Sub-Saharan Africa has a relatively plentiful supply of rainwater, with an estimated total average annual precipitation of 815 mm (FAO, 2008), but it is highly seasonal, unevenly distributed across the region (Table 7.1) and there are frequent floods and droughts. The greatest amount of rainfall occurs along the equator, especially in the area from the Niger Delta to the Congo River basin. The Sahara Desert has virtually no rainfall. In western and central Africa, rainfall is exceptionally variable and unpredictable.

At the continental level, renewable water resources constitute only about 20% of the total rainfall and represent less than 9% of global renewable resources (FAO, 2005). Internal renewable water resources per person in sub-Saharan Africa fell from an average of more than 16,500 m^3 per inhabitant in 1960 to about 5,500 m^3 per inhabitant in 2005. This was largely as a result of population growth (FAO, 2008). Groundwater represents 15% of total renewable resources, but an estimated 75% or more of the African population uses groundwater as their main source of drinking water (UNEP, 2010*b*). Because renewable resources are in short supply, capturing and storing precipitation is important. More importantly, the low volumes of renewable resources partly account for the endemic drought in areas of the continent. Although lack of access to water is mainly a function of economic scarcity (see Section 4.6.1 and Figure 4.10), significant variations both between and within subregions also contribute to the low average per capita water withdrawals of 247 m^3 per year. (FAO, 2005).

About 66% of Africa is arid or semi-arid and more than 300 of the 800 million people in sub-Saharan Africa

TABLE 7.1

Total and proportional renewable water resources in Africa's subregions

Subregion	Total water resources (km^3/year) (2008)	Percentage of internal water resources of Africa
Central Africa	2 858.08	50.66
Eastern Africa	262.04	4.64
Western Indian Ocean Islands	345.95	6.13
Northern Africa	168.66	2.99
Southern Africa	691.35	12.25
Western Africa	1 315.28	23.32
Total Africa	**5 641.36**	**100**

Source: UNEP (2010b, table 1.2, p. 15; original data from FAO AQUASTAT).

live in a water-scarce environment – meaning that they have less than 1,000 m³ per capita (NEPAD, 2006). Access to scarce water is exacerbated by increased demand caused by growing populations, especially in urban areas, and a trend towards higher living standards in some places. This is compounded by dwindling supply and poor water management. These characteristics present significant challenges to water provision in Africa and contribute to food insecurity, poor health and damaged ecosystem in many places, especially where rainfed agriculture is crucial to livelihoods (UNEP, 2010*b*).

Access to drinking water and sanitation

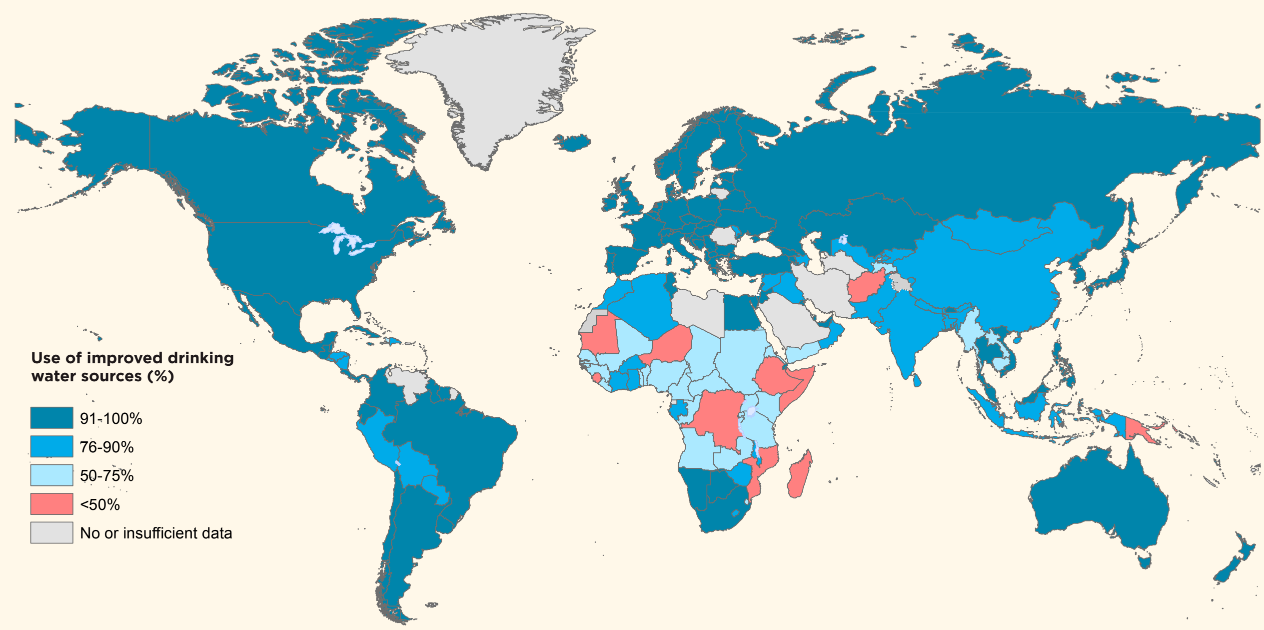
Although water is intimately linked with African culture, religion and society in myriad ways, modern African societies have not sufficiently developed the adaptive capacities they need to guarantee basic households for water and other vital services. Often, water is carried long distances, a burden borne mainly by women and children. In urban and peri-urban areas, water is often only available from vendors at an unfair price and the quality is often poor. The urban slum population in sub-Saharan African countries is expected to double, rising from 200 million in 2005 to 400 million in 2020, if governments do not take immediate and radical action (UN-Habitat, 2005).

The coverage of drinking water supply in sub-Saharan Africa[1] is barely 60%; the world average is about 87%. Of the 884 million people in the world still using unimproved drinking water sources, 37% live in this region. Provision of improved water sources in urban areas remained at 83% between 1990 and 2008. In rural areas, it was at only 47% in 2008, although this represented an 11% increase on 1990 figures, or 110 million more people gaining access to improved water supplies (WHO/UNICEF, 2010). Figure 7.1 gives a country-by-country breakdown of the proportion of the population using improved drinking water sources.

Lack of sanitation facilities is an even greater challenge to water management in Africa. Many water bodies and other sources are polluted with microbiological organisms from indiscriminate disposal of excreta, impairing human health through waterborne diseases such as diarrhoea, cholera, trachoma, schistosomiasis and others. Water-related vector-borne diseases, such as malaria, are also a major health concern. In sub-Saharan Africa, only 31% of the population uses improved

FIGURE 7.1

Use of improved drinking water sources (2008)



Source: adapted from WHO/UNICEF (2010, fig. 4, page 7).

> “About 66% of Africa is arid or semi-arid and more than 300 of the 800 million people in sub-Saharan Africa live in a water-scarce environment.”

sanitation facilities, with large differences between urban coverage, which was about 44% in 2008, and rural provision, which was 24%. Although the proportion of the population practising open defecation in the region is declining, in absolute numbers, it increased from 188 million in 1990 to 224 million in 2008 (AMCOW, 2010).

The Millennium Development Goals (MDGs) for water are to ‘halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation’. It is estimated that only five countries in sub-Saharan Africa have more than 75% of what is needed to achieve the target for drinking water and only two countries, Kenya and South Africa, have more than 75% of what is needed to achieve the sanitation target (WHO/UNICEF, 2009). The lack of safe water and proper sanitation affects not only human health and well-being, it hampers economic growth and security too.

Food insecurity

Between 2000 and 2007, 25.5% of the total population was undernourished and 30% of children under five years old suffered from malnutrition. Between the mid-1990s and 2008, undernourishment in sub-Saharan Africa increased from 200 million people to about 350 million to 400 million people (FAO, 2008). Climate change and climate variability are likely to severely compromise agricultural production and food security in many African countries (Boko et al., 2007).

Since the mid-1960s, agricultural production has increased by an average of less than 2% annually, while the population has grown by about 3% (UNECA, 2006). Some 97% of the region’s croplands depend on rainfed agriculture, which produces most of Africa’s food (FAO, 2008). Africa needs to increase its agricultural output at a rate of 3.3% a year if it is to achieve food security by 2025. Water is a key component of its ability to feed its population because irrigated cropland accounts for only 20% of its irrigation potential. In fact, in all but four countries in the region, less than 5% of the cultivated area is irrigated – so there is considerable scope for expanding irrigation to increase food security (UNEP, 2010*b*).

On the other hand, scenarios suggest that increasing the area under irrigation by a factor of three would only represent a 5% contribution to the increase in food production needed by 2025 (UN Water/Africa, 2004). However, there is even greater scope for expanding rainfed agriculture, harvesting water runoff and wisely using large untapped groundwater reserves that exist in some areas (UNEP, 2010*b*).

Energy insecurity

Sub-Saharan Africa is the world’s largest consumer of biomass energy, which includes wood, crop waste, charcoal, manure, candles and kerosene (see Section 2.2 and Chapter 19). Biomass provides 15% of South Africa’s energy consumption, 86% of energy consumption in the rest of sub-Saharan Africa, and more than 90% of the rural population’s energy consumption. Overall, only one person in four in Africa has electricity. Electricity provision is also often unreliable as a result of a lack of investment, growing demand, conflict, unpredictable and variable climatic conditions and aging equipment – all of which hampers economic activity. Hydropower supplies 32% of Africa’s energy, but it is underdeveloped. Only 3% of its renewable water resources are exploited for hydroelectricity (UNEP, 2010*b*). UNEP’s *Africa Water Atlas* notes a number of constraints to further hydro development, including the unequal capacity of Africa’s subregions. For example, despite its enormous potential for hydroelectricity generation, the Central Africa subregion is the least electrified. The *Africa Water Atlas* also notes that climate change will exacerbate rainfall variability and could hinder hydropower potential in some areas.

Africa has enough hydropower potential to meet the entire continent’s electricity needs – and boosting hydropower will stimulate the economy, improve human welfare, help the move away from biomass, produce less greenhouse gas than fossil fuels and provide a reliable base load that could enable other renewable energy resources. Developing this sector in an appropriate manner could prevent the environmental and social impacts historically associated with large dam developments (UNEP 2010*b*).

Financing for infrastructure and maintenance

Although there is a general recognition of the need to boost finance for water infrastructure across Africa, the amounts required can be difficult to determine. One of the most serious recent regional efforts at costing investment for water, sanitation and irrigation infrastructure is the Africa Infrastructure Country Diagnostic (AICD) (Foster and Briceño-Garmendia, 2010). This study is unprecedented in its efforts to analyse both the condition of infrastructure and the way to address the challenges of providing and financing infrastructure services. The study estimates that US$22 billion is needed annually by the water supply and sanitation (WSS) sector to close the infrastructure gap, meet the MDGs and achieve national targets in Africa within ten years (see Box 7.1).

The AICD report also assessed the potential investment needed for irrigation systems in Africa, reported to be approximately US$18 billion for small-scale irrigation systems and US$2.7 billion for large-scale systems over a fifty year investment horizon (Box 7.2).

BOX 7.1

Africa's WSS investment needs

An annual investment of about US$22 billion (roughly 3.3% of Africa's GDP) is the estimated requirement for Africa to meet the water and sanitation MDGs. Projections were built on a base scenario, which assumes the same distribution across modalities as 2006 and applies in both urban and rural areas

Water and sanitation spending needs, 2006–2015, US$ billion per annum

	Total	Investment	Maintenance
Water	17.2	11.5	5.7
Sanitation	5.4	3.9	1.4
Total	22.6	15.4	6.1

Capital investment needs were estimated at US$15 billion a year – around 2.2% of the region's GDP. Capital outlay estimates, which include both new infrastructure and the rehabilitation of existing assets, are based on minimum acceptable asset standards. In addition, it is assumed that access patterns (or relative prevalence of water and sanitation modalities) remain broadly the same between 2006 and 2015 and that services are upgraded for only a minimum number of customers.

Maintenance requirements stand at about US$6 billion per annum (1.1% of GDP). Operation and maintenance of network and non-network services amount to 3% and 1.5% respectively of the replacement value of installed infrastructure. Rehabilitation estimates were based on a model that takes into account the maintenance backlog of network infrastructure in each country.

Source: Foster and Briceño-Garmendia (2010).

Transboundary water management

Africa has about one-third of the world's major international water basins – basins larger than 100,000 km². Virtually all sub-Saharan African countries, plus Egypt, share at least one international water basin. Depending on how they are delineated, there are between 63 (UNEP, 2010*b*) and 80 (UNECA, 2000) transboundary river and lake basins on the African continent. Water interdependency is accentuated by the fact that high percentages of total flows in downstream countries originate outside their borders (UNECA, 2001). Often, downstream countries are at a disadvantage in comparison with their upstream neighbours. Examples of this occur in the Niger basin, the Juba–Shabelle basin and the Okavango basin.

Another challenge facing transboundary water management is the lack of complete, reliable and consistent data about transboundary water resources, especially groundwater (Box 7.3). Thus, there is a potential for conflict over these waters. Nevertheless, there are also over 90 international water agreements that were drawn up to help manage shared water basins on the African continent (UNEP, 2010*b*). For example, the 2000 Southern African Development Community (SADC) Protocol on Shared Watercourses (SADC, 2008) promotes the setting up of shared watercourse agreements. It also institutionalizes and enshrines the principles of reasonable use and environmentally sound resource development.

Another African model is the Nile Basin Initiative. Formally launched in February 1999 by the Council of Ministers of Water Affairs of the Nile Basin States, it 'seeks to develop the river in a cooperative manner, share substantial socio-economic benefits, and promote regional peace and security' (UNEP, 2009, p. 50).

Climate change and extreme events

The Intergovernmental Panel on Climate Change (IPCC) states with very high confidence that 'Climate change will aggravate the water stress currently faced by some countries, while some countries that currently do not experience water stress will become at risk of water stress' (Boko et al., 2007, p. 435). A growing body of evidence links unmitigated hydro-climatic variability to poor economic growth in developing countries, especially in Africa. In most poor countries, climate variability is high, infrastructure is poor and GDP is correlated with rainfall.

Drought is the dominant climate risk in sub-Saharan Africa. It destroys economic livelihoods and farmers' food sources and has a significant negative effect on GDP growth in one-third of the countries. For example, in Kenya, the drought associated with La Niña between 1998 and 2000 caused a 6% reduction in GDP. Floods are also highly destructive to infrastructure, transport

BOX 7.2

Africa's irrigation investment needs

Two categories of irrigation development were assessed looking at a fifty year investment horizon:

- Large-scale, dam-based irrigation category was associated with hydropower reservoirs identified by a companion study for hydropower. This irrigation assumed a medium investment cost of US$3,000 per ha for on-farm development; US$0.25 per m^3 for water delivery and conveyance; a proxy for canal operations and maintenance; and US$10 per ha for on-farm operations and maintenance. Dam costs were not included because they are assumed to be fully justified and fully covered by the hydropower schemes associated with the relevant dams.
- Small-scale irrigation was based on small reservoirs, farm ponds, treadle pumps, and water-harvesting structures that collect local runoff. These assumed a five-year investment cycle, a medium investment cost of US$2,000 per ha for on-farm investment, and US$80 per ha for operation and maintenance.

Crop prices, based on commodity-specific world prices for 2004–2006, were adjusted for country differences in price policy and market transaction costs.

The estimates were based on a spatial analysis study that combined hydro-geographic and economic parameters to estimate the potential investments needs for irrigation.

	Large-scale irrigation			Small-scale irrigation		
	Increase in irrigated area (million ha)	Investment cost ($ million)	Average IRR (%)	Increase in irrigated area (million ha)	Investment cost ($ million)	Average IRR (%)
Sudano-Sahelian	0.26	508	14	1.26	4 391	33
Eastern	0.25	482	18	1.08	3 873	28
Gulf of Guinea	0.61	1 188	18	2.61	8 233	22
Central	0.00	4	12	0.30	881	29
Southern	0.23	458	16	0.19	413	13
Indian Ocean Islands	0.00	0.00	–	0.00	0.00	–
Total	**1.35**	**2 640**	**17**	**5.44**	**17 790**	**26**

Note:
Sudano-Sahelian: *Burkina Faso, Cape Verde, Chad, Niger, Senegal, South Sudan and Sudan*
Eastern: *Ethiopia, Kenya, Rwanda, Tanzania and Uganda*
Gulf of Guinea: *Benin, Côte d'Ivoire, Ghana and Nigeria*
Central: *Cameroon and the Democratic Republic of Congo*
Southern: *Lesotho, Malawi, Mozambique, Namibia, South Africa and Zambia*
Indian Ocean Islands: *Madagascar*
Source: Foster and Briceño-Garmendia (2010, table 15.2, p. 291); You (2008).

and goods and service flows, and they can contaminate water supplies and cause epidemics of water-borne diseases such as cholera.

In the Mozambique floods of 2000, over 2 million people were affected, and damages were estimated at 20% of GDP (Brown and Hansen, 2008). Throughout sub-Saharan Africa, the effect of these hydrological extremes can be devastating, especially where there is high dependence on agriculture and where infrastructure is deficient. In the coming decades, when the impact of climate change is likely to worsen, droughts and floods associated with climate variability will continue to ravage vulnerable communities in African countries.

Although African farmers have already developed techniques to adapt to inherent weather variations, these may not be sufficient to adapt to the combined impacts of the interaction of multiple stresses at various levels caused by climate change and climate variability (Boko et al., 2007).

Data challenges

Insufficient, inconsistent and unreliable data about water, water needs (from socio-economic indices) and weather-related extreme events are among the key challenges facing Africa as the continent tries to manage its water resources (Young et al., 2009). For example, economic planners factor assumptions about demographic changes such as population growth and urbanization, into national plans despite high levels of uncertainty. This is especially evident in instances where there are disputes over the results of population censuses that arise out of ethnic, religious or political considerations. The *Africa Water Atlas* notes that, 'Building on a foundation of detailed, consistent, accurate and available data is one of the central challenges for Africa's water future' (UNEP, 2010b, p. 38). In the case of scientific information, for example, the sustainable use of the groundwater resources that underlie the Lake Chad basin is hampered by a lack of hydro-geological datasets (Box 7.3).

7.1.3 Response measures

Institutional, legal and planning responses

African Union initiatives – such as the African Ministers' Council on Water (AMCOW), the African Water Facility, the increasingly important African Development Bank (AfDB) and the Rural Water and Sanitation Initiative – all vividly testify to ongoing commitment to

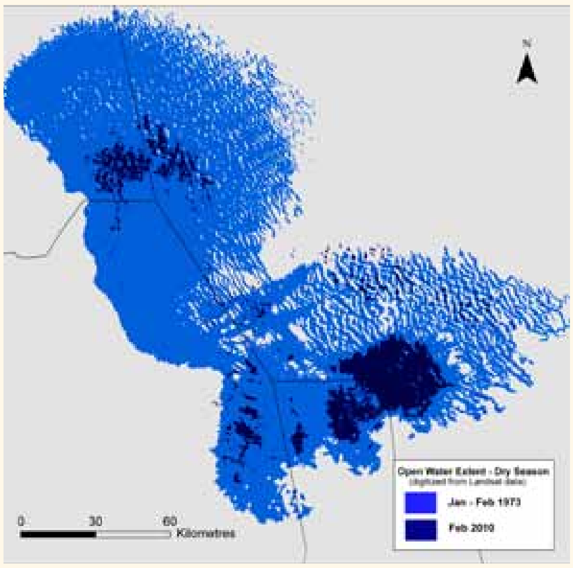
BOX 7.3

Groundwater resources in the Lake Chad basin

Lake Chad is one of the Sahel's largest freshwater reservoirs, and a focal point for more than 3 million people – most of whom farm, herd animals and fish for a living, and who live within a 200-km radius of the lake. Seasonal, yearly and decadal rainfall is extremely variable across this region. The basin is fed by the Chari, Logone and Komadougou Yobé rivers, but since the mid-1960s, droughts, water diversions and irrigation have led to a 75% drop in water flows (see the figure). Ecosystems have been unable to adapt fast enough, fishing communities have had to move away and the quality and coverage of dry-season grazing has declined.

Some 35 million people in the larger Lake Chad basin have been affected to some degree. Water shortages have caused the increased use of groundwater, although some studies suggest that declining precipitation has also affected water levels in the Quaternary aquifer that underlies the Lake Chad basin. There is not enough information about the groundwater reserves, however, and there is an urgent need to improve the availability and completeness of hydro-geological datasets so policy-makers can respond appropriately to the Lake Chad basin's diminishing water resources (UNEP, 2010b).

Approximate extent of open water in Lake Chad digitized from Landsat images, 1973–2010



Source: UNEP (2010b, p. 49)

water-related development. One of the most important events was the Second Extraordinary Session of Heads of State and Governments of the African Union, which was held in Sirte, Libya, in February 2004 and dedicated to agriculture and water. Another important event was the African Union Summit of Heads of State on Water and Sanitation in Sharm el-Sheikh, Egypt in July 2007. The Africa Water Week, under the auspices of AMCOW, has added another impetus to information sharing and awareness of water resources development and management. However, there is an urgent need for wider international cooperation to augment regional and continent-wide efforts in line with the ongoing collaboration with the European Union (EU). Though in many instances, transboundary agreements have been successful in addressing potential conflicts over shared waters (Box 7.4).

African nations have also begun to seek ways to address transboundary water issues related to hydropower development, especially by fostering regional integration through power pools such as the South African Power Pool (SAPP) and the West African Power Pool (WAPP). Using such pools, countries can reduce their costs while maintaining their own power supply, rely on mutual help when power systems break down, enjoy social and environmental benefits, and strengthen cross-border relationships (UNEP, 2010*b*).

BOX 7.4

Joint management of the Senegal River

Potential conflict was averted in the Senegal River basin when a constructive compromise was reached on joint management. This was made possible through the establishment of the Organization for the Development of the Senegal River (OMVS) in 1972; through the adoption of the Senegal River Charter in 2002; and by using a financing mechanism to ensure the generation of revenues and benefits for the four basin countries.

Agreements in the Lake Chad basin have not been as inclusive because some riparians are not party to the 2008 legal agreement and strategic action programme for Lake Chad. Within the transboundary agreements that are in operation, it is still necessary to improve understanding and clarify regional perspectives on international water law principles.

Africa-wide efforts are being taken to address the uncertainty of climate change. African climate institutions – such as the African Centre of Meteorological Applications for Development; the Inter-Governmental Authority on Development's (IGAD's), Climate Prediction and Applications Centre (ICPAC); and the Southern African Development Community (SADC) Drought Monitoring Centre – have worked on the climate risk management approach in collaboration with the International Research Institute for Climate and Society. They are building capacities for its smooth integration into sectoral decision-making processes such as agricultural production, food security, water resources management, health protection and disaster risk management. These climate institutions also help to synchronize regional legal frameworks that protect and sustain shared water resources through a benefit-sharing paradigm. And they can arrange inter-basin water transfer schemes to save dying water ecosystems like Lake Chad (see the figure in Box 7.3) or transfer water from water-rich basins to drier zones.

Concerted efforts at the regional, continental and international levels can help African countries to face the challenging task of harnessing water resources for sustainable development in the face of climate variability and change. It is therefore important to pool all human and institutional resources in order to tackle common challenges by improving the understanding of and quantitative knowledge about the various sources of uncertainty. It is also important to improve the way this knowledge is communicated to water resources managers and other stakeholders, and the way uncertainty is incorporated into water resources management decision-making (Hughes, 2008).

The challenges are not all infrastructural. They also include early-warning systems to help predict the onset of and duration of rainfall seasons, intra-seasonal dry spells, rainfall anomalies based on inter-hemispherical teleconnections, and lead times on the impacts of El Niño and La Niña.

7.2 Europe and North America

The United Nations Economic Commission for Europe (UNECE) region comprises the 56 countries of the European Union; Western, Central and Eastern Europe; the Caucasus; Central Asia; and North America, which comprises the United States of America (USA) and Canada (see Map 7.2).

Dams and diversions that were built to provide hydropower and irrigation and to manage floods have significantly altered the region's watersheds. While dams, weirs and diversions provide water management services, they have also changed hydrological regimes, interrupted river and habitat continuity, disconnected rivers from adjacent wetlands and floodplains, and changed erosion processes and sediment transport. Most point-source pollution from industrial and municipal effluent has been addressed in the most developed countries, but discharges of untreated or insufficiently treated wastewaters continue to exert pressures, especially in Eastern Europe, South-Eastern Europe (SEE), the Caucasus and Central Asia.

Nutrients from agricultural runoff, however, are of growing concern throughout the UNECE region. Moreover, pressures from irrigated agriculture to extract water are rising, especially in more water scarce parts of the region, as are demands to satisfy growing urban needs. Meanwhile climate change is threatening available water resources and leading to increased competition among users. Some parts of the region are subject to floods and droughts, and climate change is exacerbating these threats.

All the region's nations except three island states share water resources with at least one other country, and transboundary watersheds cover more than 40% of the European and Asian parts of the UNECE region (UNECE, 2007*a*). There are more than 100 transboundary rivers, with a basin area over 1,000 km^2 each, and over 100 transboundary groundwater aquifers (UNECE, 2011*a*). This has led to strengthened bilateral and multilateral cooperation and agreement on these shared waters.

There is a marked difference in the state of water quality and management between the countries of the EU and North America, and those in Eastern Europe and Central Asia. There is a long history of environmental legislation, including water management, in the EU and North America, through Conventions and Protocols, supplemented by regulations, recommendations and guidelines for action. Eastern Europe, the Caucasus and Central Asia, as well as a number of new EU countries, are still struggling to adequately manage water provision and pollution.

7.2.1 The driving forces and pressures on water resources

Population, affluence and poverty

More than 1.2 billion people live in Europe and North America, with the latter representing just over one-third of the total. Between 1960 and 2000, Central Asia (more than 120% population increase) and the Caucasus (60% increase) have experienced considerably higher growth rates than other countries. For most countries in Western and Central Europe, populations are stable or declining (PRB, 2008). People are permanently or seasonally migrating from many Eastern European countries to western cities where economic prospects are better.

In North America, the population of the USA grew by 9.7% between 2000 and 2010, and it is expected to increase by more than 50% in the 60-year period from 1990 to 2050 (US Census Bureau, n.d.). Total water withdrawals in the USA grew between 1970 and 1980, declined by more than 9% between 1980 and 1985, and have been relatively constant since then despite continued population growth (National Atlas of the United States, 2011). In Canada, total water withdrawals have been rising steadily (CEC, 2008). In 24 European countries, total water abstraction decreased about 12% over the past 10–17 years, but one-fifth of Europe's population (approximately 113 million inhabitants) still lives in water-stressed countries (EEA, 2010).

European and North American populations also consume a considerable amount of virtual water embedded in imported food and products. According to one calculation, each person in North America and Europe (excluding former Soviet Union countries) consumes at least 3 m^3 per day of virtual water in imported food, compared to 1.4 m^3 per day in Asia and 1.1 m^3 per day in Africa (Zimmer and Renault, n.d.).

The per capita water used for food production in Western Europe and North America has decreased substantially in past decades (Renault, 2002).

Reductions in total water consumption are due to increased efficiency, economic factors, regulations and increased awareness of the need to conserve water. The economies of countries in transition in Europe are still catching up, but with increasingly high living standards, consumption is projected to rise.

The contribution made by primary production and heavy industry to the economies of Western and Central Europe and North America has fallen, while that of service industries and knowledge-based industries has risen. With this has come a decline in point-source water pollution (UNEP, 2006*b*). Despite the marked transition to a post-industrial economy, demand for water is likely to remain high in Eastern Europe, Central Asia and the Caucasus because of the dependence on agriculture, mining and other export commodities. The poor in lower-income countries such as Armenia, Georgia, Uzbekistan, the Republic of Moldova, Kyrgyzstan and Tajikistan are often unable to afford basic domestic water services.

MAP 7.2

UNECE Member States

Source: Economic Commission for Europe, Map No. 3976 Rev. 11, November 2011. Department of Field Support, Cartographic Section, United Nations.
Note: North America members are listed but not shown on the map.
For the purposes of this chapter, the UNECE Member States are divided into the following groupings:
***EU countries:** Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.*
***Western Europe:** Andorra, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Sweden, Switzerland, United Kingdom.*
***Western Europe EU-15 countries:** Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.*
***Central and Eastern Europe:** Albania, Bosnia and Herzegovina, Bulgaria, Czech Republic, Croatia, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Montenegro, Poland, Romania, Serbia, Slovakia, Slovenia, the former Yugoslav Republic of Macedonia, Turkey.*
***Central and Eastern Europe countries that became EU Member States in the course of the EU enlargement process:** Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia.*
***Balkan countries (as a subgroup of Central and Eastern Europe):** Albania, Bosnia and Herzegovina, Croatia, Republic of Macedonia, Montenegro, Serbia.*
***Mediterranean:** Albania, Bosnia and Herzegovina, Croatia, Cyprus, France, Greece, Israel, Italy, Malta, Monaco, Montenegro, Portugal, Serbia, Slovenia, Spain, Turkey.*
***Eastern Europe, the Caucasus and Central Asia:** Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.*
***The Caucasus:** Armenia, Azerbaijan, Georgia.*
***Central Asia:** Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.*
***North America:** Canada, United States of America.*

Climate change

Europe and North America make a disproportionately high contribution to climate change. The Intergovernmental Panel on Climate Change (IPCC) states that 'freshwater resources are vulnerable and have the potential to be strongly impacted by climate change' (Bates et al., 2008, p. 135). High northern latitudes are expected to experience the most extreme warming, increasing the risk for indigenous peoples in the Arctic as snow and ice conditions change dramatically. The poorest and most vulnerable are likely to suffer the most, since they have fewer resources with which to cope.

Projections vary considerably across the UNECE region, but climate change is expected to bring higher temperatures, drought, reduced water availability and lower crop yields to Southern Europe, the Caucasus and Central Asia. Hydropower potential and summer tourism are also likely to be affected. In Central and Eastern Europe, summer precipitation is projected to decrease, causing higher water stress. While climate change is likely to have positive effects in the short term in Northern Europe, these are expected to be outweighed by negative effects as climate change progresses (UNECE, 2009*a*).

North America is expected to experience warmer temperatures, increased rainfall, summertime droughts and more intense and frequent extreme weather events such as tornadoes and hurricanes. The risks and uncertainties associated with climate change impacts are discussed later.

Water and agriculture

Agricultural practice in the region has changed considerably over the past decades: mechanization, increased use of fertilizers and pesticides, farm specialization, growth of farm size, land drainage and developments in animal husbandry have led to adverse impacts on the aquatic environment with some specific subregional differentiation of water use and water pollution. Water use for crop and animal production, for example, in Central Asia, Greece, Italy, Portugal and Spain, accounts for 50–60% of the total use. In other countries, agriculture accounts for only around 20%, while the bulk is used by manufacturing industries and for cooling purposes.

Agrochemicals have had a detrimental effect on water resources throughout the region as nitrogen, phosphorus and pesticides run into water courses. In Eastern Europe, the Caucasus and Central Asia, these diffuse pressures are 'widespread but moderate' (UNECE, 2007*a*, 2011*a*). As the economy revives, however, they will increase, threatening domestic and transboundary waters as well as human health. In some basins, particularly in Central Asia, irrigation has led to soil salinization and high levels of mineral salt in water bodies (Box 7.5).

> "European and North American populations also consume a considerable amount of virtual water embedded in imported food and products."

Since the 1960s, land under irrigation has doubled in Canada, and has increased by more than 50% in the USA, with much of the growth in arid or semi-arid regions. In many parts, groundwater levels are declining as withdrawals outweigh recharge (CEC, 2008). Since the 1950s, nitrate loads from agricultural runoff have increased enormously in the Mississippi River, which drains more than 40% of the land mass of the USA's 48 contiguous states (EPA, 2008).

The legal frameworks and best management practices to reduce pollution from agriculture were established some time ago in the EU and in North America. In EU countries in the drainage basins of the Mediterranean Sea, the eastern Atlantic Ocean, and the Black Sea, implementation of these frameworks and practices is lagging, and water quality is still suffering. High applications of both mineral and organic fertilizer are used in the farming areas of Western Europe. Source apportionment studies indicate that agriculture generally provides 50–80% of the total nitrogen load, with wastewater providing most of the remainder (EEA, 2005). Nitrogen application rates had increased dramatically over past decades, but are now widely declining. However, it takes a long time for this to translate into reduction in the concentration of nitrogen compounds in water bodies (UNECE, 2011*a*).

Water in the industrial and municipal sectors

Modern pollution abatement technologies have stemmed the most egregious pollution from large industrial processes in Western Europe and North America. Recent concerns relate to modern chemicals, including new pharmaceuticals and hormones. Pollution from the great number of small and medium-sized industries and small municipal wastewater treatment plants in Eastern Europe, the Caucasus, Central Asia and several of the new EU countries, which do not operate according to standards, are still important sources of water pollution (Box 7.6). Despite assistance from Western Europe, the impact of economic decline in the 1990s remains visible as wastewater treatment is still inadequate and waters continue to be polluted with heavy metals, phosphorus, nitrogen and oil products (EEA, 2010). Mining has an impact more locally in SEE, in the Caucasus and some areas in Northern Europe.

BOX 7.5

Agriculture and water use in Central Asia

In Central Asia, the agricultural sector accounts for more than 90% of surface water extracted and 43% of groundwater extracted, but it supports half the regional population. Irrigated agriculture and the entire water-based sector contribute about 40% to 45% of regional GDP (Stulina, 2009). Central Asia represents 50% of the total irrigated area of the regions of the former Soviet Union, (FAO, 2011).

Agricultural water pollution, sedimentation and algae blooms have had some serious and well-documented impacts. These have included the loss of biodiversity, the extinction of whole ecosystems, a deterioration in drinking water quality, human health problems, declining crop yields, poverty, unemployment, migration and the risk of conflict (Yessekin, et al. 2006). Although many measures have been taken to address the situation, scarce financial resources have led to delays in implementing them. The importance of stakeholder involvement in negotiating water allocation, especially in transboundary situations, has only recently been recognized. The International Fund for Saving the Aral Sea is steering a process to improve conditions.

Infrastructural changes to water courses

Throughout the region, structural modifications to watersheds have altered natural flows, disrupted or destroyed wildlife habitats and ecosystem services, and disconnected rivers from their floodplains – and so increasing the risk of floods in many places. Some countries have plans to re-naturalize water courses. In Western and Central Europe, partly because there the degree to which water bodies have been modified has been assessed, there is a higher awareness about the issue and response measures have started to be taken to address it. Considerable time and financial resources are needed to restore, for example, rivers in the Danube basin (see Box 30.5, 'Hydromorphological alterations in the Danube Basin', in Chapter 30). Current economic conditions and prospects are delaying the process.

The US Environmental Protection Agency is providing grants to some states to restore rivers and streams, while there is a growing movement to remove dams where the environmental and other costs outweigh the benefits (American Rivers, n.d.).

The Danube, in the basin of which courses of rivers have been changed for hydropower generation, flood defence and navigation since the sixteenth

BOX 7.6

Wastewater treatment infrastructure in the Republic of Moldova

The 1990s economic downturn resulted in a huge decline in the operational capacity of Moldova's municipal wastewater treatment plants. By 2010, only 24% were still operating and only 4% of these were adhering to legal requirements for the disposal of wastewater. In rural areas, 70% of homes were not connected to the sewerage system. As a result, an increasing amount of untreated wastewater was discharged into rivers. EU and other funds began supporting an enormous assistance programme to rehabilitate municipal infrastructure and improve rural sanitation. New wastewater treatment legislation, modelled on EU laws and drawn up under the National Policy Dialogue process came into force in October 2008, replacing outdated Soviet-style law. Existing plants can now be rehabilitated and new ones constructed according to state-of-the-art treatment technology (UNECE, 2011*b*).

century, has hydropower impoundments along 30% of its length. It is now subject to plans to improve ecosystem quality in accordance with the Danube River Protection Convention, which came into force in 1998 and addresses hydropower as well as polluted discharges from agriculture, municipalities and so forth (ICPDR, 2007). In Western Europe, the Water Framework Directive has led to programmes to enhance and protect aquatic ecosystem services, and the innovative Payment for Ecosystem Services approach is being explored in the UNECE region (Wunder, 2005; UNECE, 2005).

Table 7.2 summarizes the relative importance of these various pressures on water resources over subregions (UNECE, 2007*a*). As economies grow or revive, however, shifts in the relative importance of some of these pressures will occur, especially in Eastern Europe, the Caucasus and Central Asia.

7.2.2 Challenges, risks and uncertainties

The situations and places in which uncertainty and risk are most evident in Europe and North America include highly populated areas that are prone to flooding and drought. The projected impacts of climate change also include increased risks of extreme hydrological events. Uncertainty and risk can lead to conflict in conditions where limited amounts of declining or increasingly polluted water resources are shared between sectors or among different populations in situations that are also changing, such as in burgeoning urban areas. A particular challenge for countries in Eastern Europe and Central Asia is water use efficiency in irrigated agriculture. Finally, human health is at risk where water and sanitation provision is inadequate.

Floods and drought

Overabstraction, water scarcity and drought have a direct impact on citizens and economic sectors, and large areas of Europe and North America are already affected (Boxes 7.7 and 7.8). Climate change will bring higher temperatures to the region, exacerbating drought events.

Between 1976 and 2006 in the EU, both the area affected by drought and the number of people whose lives were influenced doubled (Figure 7.2). These impacts can include declines in cereal and hydropower production (as exemplified by the situation in Russia in 2010), and economic repercussions. Many Western European countries have drawn up or are preparing drought management plans (EC, 2009). To address the impact of drought and water scarcity on human health, UNECE and WHO/Europe have developed specific guidance and recommendations, which include adaptation measures for drainage, sewerage and wastewater treatment (UNECE, 2009*a*).

TABLE 7.2

Main pressures on water resources in order of priority (from high to low)

Countries in Eastern Europe, the Caucasus and Central Asia	EU-15 countries and North America
Pressures on water quality: Municipal sewage treatment, non-sewer population, old industrial installations, illegal wastewater discharges, illegal disposal of household and industrial wastes in river basins, tailing dams and dangerous landfills	Pressures on water quality: Agricultural (especially nitrogen) and urban sources of pollution
Abstraction pressures: Agricultural water use	Abstraction pressures: Agricultural water use (particularly in Southern Europe and the south-western USA), major urban centres
Hydromorphological alterations: Hydropower dams, irrigation channels, river alterations	Hydromorphological alterations: Hydropower dams, river alterations
Other pressures: Agro-chemical pollution (becoming more severe), mining and quarrying	Other pressures: Selected industries discharging hazardous substances, mining and quarrying

Source: Chapter 30.

Floods have affected more than 3 million people in the UNECE region since the beginning of the century, and the associated costs have increased rapidly. They have exposed people to various health hazards and caused deaths, displacement, and economic losses. Contributing factors include population growth in flood-prone areas, deforestation and wetland loss. Recognizing the benefits of natural flooding to ecosystems and the role of wetlands in flood protection has led to a shift towards an integrated approach to flood management in many European countries and in North America. A number of transboundary watersheds have initiated integrated water management plans (Roy et al., 2010; UNECE, 2009*b*).

Climate change and uncertainty and risk

The IPCC predicts with high confidence that water stress will increase in Central and Southern Europe, and that by the 2070s, the number of people affected will rise from 28 million to 44 million. Summer flows are likely to drop by up to 80% in Southern Europe and some parts of Central and Eastern Europe. Europe's hydropower potential is expected to drop by an average of 6%, but rise by between 20% and 50% around the Mediterranean by 2070 (Alcamo, et al. 2007). In North America, the IPCC reports with high confidence that the impact will include increased competition among users for over-allocated water resources. Climate change will also stress the bi-national relationship over the shared Great Lakes[2], where water levels are likely to decline and population growth will fuel demand (Field et al., 2007). Much uncertainty exists about how national water management bodies in the region can adapt to these changes, especially where financial and human capacities are constrained by widespread poverty, as in Eastern Europe, the Caucasus and Central Asia. In addition, climate mitigation measures may produce adverse side effects for water management, heightening uncertainty and risk (UNECE, 2009*a*). One example is the debate over water for food production versus water for bio-energy crops.

Water and human health

Some 120 million people in the European region do not have access to safe drinking water. Even more lack access to sanitation, resulting in the spread of water-related diseases. In North America, native peoples are often ill-served by piped water and sanitation facilities. For example, over 10,000 homes on reserves in Canada have no indoor plumbing, and the water or sewer systems in one reserve in four are substandard (UNDESA, 2009).

Concerted international efforts to address water-related health matters in the region only began at the end of the 1990s, culminating in the Protocol

BOX 7.7

Uncertainty and risk on the North American prairies

In the prairies of Canada and parts of the United States of America, water flows are highly variable, which is reflected in the occurrence of severe floods and drought. The lack of predictability, exacerbated by melting glaciers and snowpacks (as a result of climate change), affects the economy and has led to competition for water between agriculture, the oil and gas industries and growing municipalities. Watershed planning and management strategies have been instituted to attempt to address the risks associated with the changing conditions, which include a decline in water yield of 20 km^3 between 1971 and 2004 in the Canadian Prairies (UNEP, 2007; Statistics Canada, 2010).

BOX 7.8

Satisfying municipal water needs in drought-prone regions

In dry years, there have been problems supplying sufficient water to the 12 million people living in Istanbul and the 4 million inhabitants of Ankara. As a result, water has been rationed. In response to the IPCC's projection that demand in Istanbul will rise while supply falls, a number of remedial actions are being taken, from water saving campaigns to water transfers from as much as 150 km away (Waterwiki.net, n.d.).

During the 2008 drought, Barcelona turned off civic fountains and beachside showers and banned hosepipes and filling swimming pools. In the same year, Cyprus applied emergency measures that included cutting the water supply by 30% (EEA, 2007, 2010). In a growing number of cities, such severe emergency restrictions became part of a consultative process with stakeholders, a change that was also influenced by the requirements of the Aarhus Convention (UNECE, 1998).

on Water and Health under the UNECE Water Convention. This is dedicated to ensuring that everyone has adequate drinking water and sanitation. It has resulted in increased efforts to attain, and move beyond, the water-related MDGs (UNECE, 2010). Basin organizations, such as those for the Rhine, Meuse, Scheldt and Danube, also challenge the basin countries to develop a more coordinated approach and address the effects that pose the highest risk and uncertainties to human health and water management, and to develop appropriate adaptation measures to new risks as they become better understood (UNECE, 2011*a*).

7.2.3 Response measures

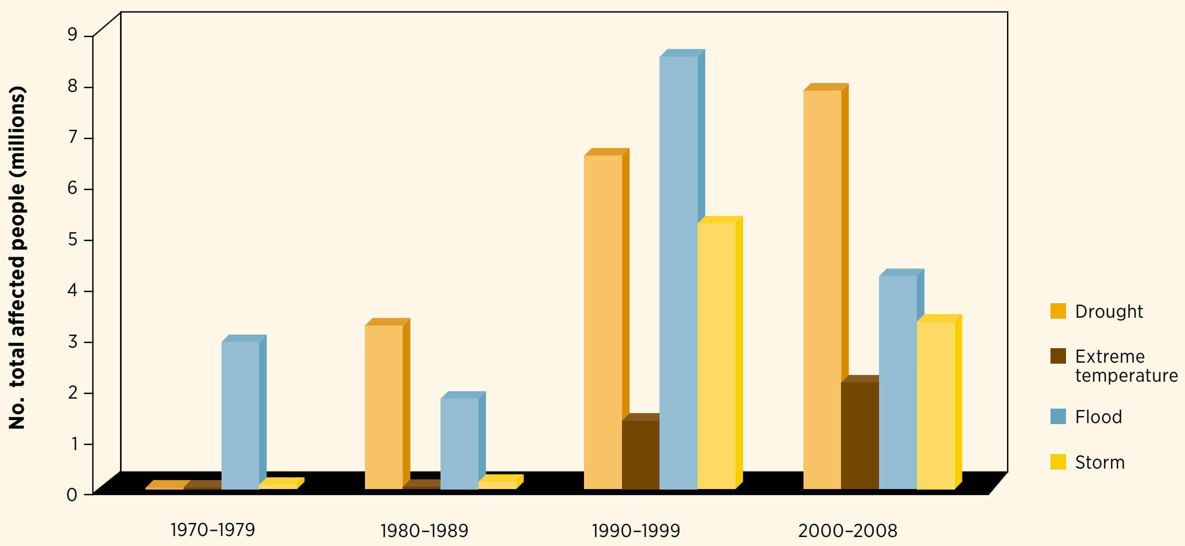
Institutional, legal and planning responses

Institutional and strategic responses to manage water issues have a relatively long history in the region. In North America, water governance was strengthened in the 1970s with the passing of regulations such as the Clean Water Act and the Safe Drinking Water Act in the USA, and parallel legislation in Canada, including the Canada Water Act. In Canada, however, water governance is generally more decentralized and fragmented as a result of the constitutional division of powers between provincial and federal governments. There were recent demands for a federal water policy – a four-year project running from 2008 to 2012 to create a Water Security Framework (Norman et al., 2010). There has been a recent devolution of water governance from federal to state levels in the USA, which has led to an increase in local participation in water management (Norman and Bakker, 2005).

Water-related institutions in countries in transition are still generally weak, with water competences spread among institutions with weak enforcement capacities. Supported by the EU on many fronts, new EU Member States have made better progress in building new institutional structures in comparison with other Eastern European countries, the Caucasus and Central Asia (UNECE, 2010). The Water Framework Directive (WFD), which was concluded in 2000 apart from some more recent directives on standards and groundwater, is the most important piece of EU water legislation (EC, 2000). Other directives with direct relevance to water quality and its protection are the ones related to urban wastewater treatment (1991), to control and limit nitrate pollution from agriculture (1991), to regulate the quality of drinking water (1998), and to other

FIGURE 7.2

Number of people affected by selected extreme weather events in the UNECE region, 1970–2008



Note: At least one of the following criteria must be fulfilled: 10 or more people reported killed; 100 people reported affected; declaration of a state of emergency; or call for international assistance.
Source: Produced in 2009 by the Italian National Institute for Environmental Protection and Research (ISPRA) based on data from the EM-DAT database by the Centre for Research on the Epidemiology of Disasters (CRED) at the Catholic University of Louvain.

areas related to water and health issues. The WFD expands the scope of water protection to all waters, and requires the achievement of a 'good status' for all waters in EU countries by 2015. Apart from its effect to improve water management in EU countries, the application of principles of the WFD is of immense importance to improving water management and cutting down pollution in countries at the Eastern border of the EU (Belarus, the Republic of Moldova, Ukraine, Armenia, Azerbaijan and Georgia).

The use of transboundary waters, and their protection, is governed by the 1992 UNECE Water Convention. This requires parties to enter into specific bilateral or multilateral agreements and to create joint institutions. The EU Water Framework Directive (WFD) has accelerated and deepened a historical process of transboundary water management across the EU's 40 international river basins, exemplified in the Danube and Rhine basins (EC, 2008).

Canada and the USA have been leaders in the bilateral management of shared waters, through the International Joint Commission in particular. As a result, the status of many watercourses in the regions has been considerably improved, and there are far fewer disputes over shared waters (UNECE, 2009*c*). Addressing transboundary groundwater issues remains an exception, as the work of many joint bodies in the area of transboundary groundwaters is still insufficient, except perhaps in some parts of Western Europe.

7.3 Asia-Pacific

For the purposes of this chapter, the Asia-Pacific region[3] comprises the 55 member states of ESCAP in five subregions: Central Asia, North-East Asia, Oceania and the Pacific, South Asia, and South-East Asia (see Map 7.3 for the ESCAP Member Countries). The region is extremely diverse, with seven of the world's most populous countries and many of its smallest nations, several of which are located in the Pacific (ESCAP, 2011).

The Asia-Pacific is home to 60% of the world's population but it has only 36% of its water resources (APWF, 2009). Nevertheless, this represents the world's largest share of renewable freshwater resources, with an annual average of 21,135 billion m^3. Given its large population and economic growth, its water withdrawal rate is also high, averaging about 11% of its total renewable water resources, which is on par with European rates, and ranks it second in the world after the water-scarce Middle East (ESCAP, 2010*a*). Per capita availability here is the lowest in the world (ESCAP, ADB and UNDP, 2010).

The region includes the Russian Federation, India and China, three of the five BRICS countries, with their increasing water demands to support their burgeoning economic development. Growing populations, rapid urbanization, industrialization, economic development and climate change continue to put pressure on the region's freshwater resources, exacerbating already difficult conditions. The Asia-Pacific's socio-economic development pattern previously relied primarily on cheap natural and human resources. The consequences have been two parallel economies: rapid advances in economic performance alongside persisting poverty and environmental degradation.

Between 1990 and 2008, significant achievements were made in meeting the MDG on access to safe drinking water. But progress has generally been slower in providing improved sanitation, except in North-East and South-East Asia. About 480 million people still lacked access to improved water resources in 2008, while 1.9 billion still lacked access to improved sanitation.[4] Even when access is established, natural disasters and functionality levels can significantly influence whether or not drinking water and sanitation systems can continue to respond to the region's needs. The Asia-Pacific is highly vulnerable to extreme events and climate change is expected to increase climate variability and the magnitude and frequency of floods and droughts.

Water availability, allocation and quality remain major issues. Irrigated agriculture is the biggest water user. Some countries, such as Cambodia and Lao People's Democratic Republic, use less than 1% of their total available water resources, while others have withdrawn significant quantities of their total combined surface water and groundwater – in one case leading to the disaster at the Aral Sea. Population growth, growing water consumption rates, environmental degradation, damaging agricultural activities, poor catchment area management, industrialization, and groundwater overuse are causing a deterioration in water quality.

7.3.1 The driving forces and pressures on water resources

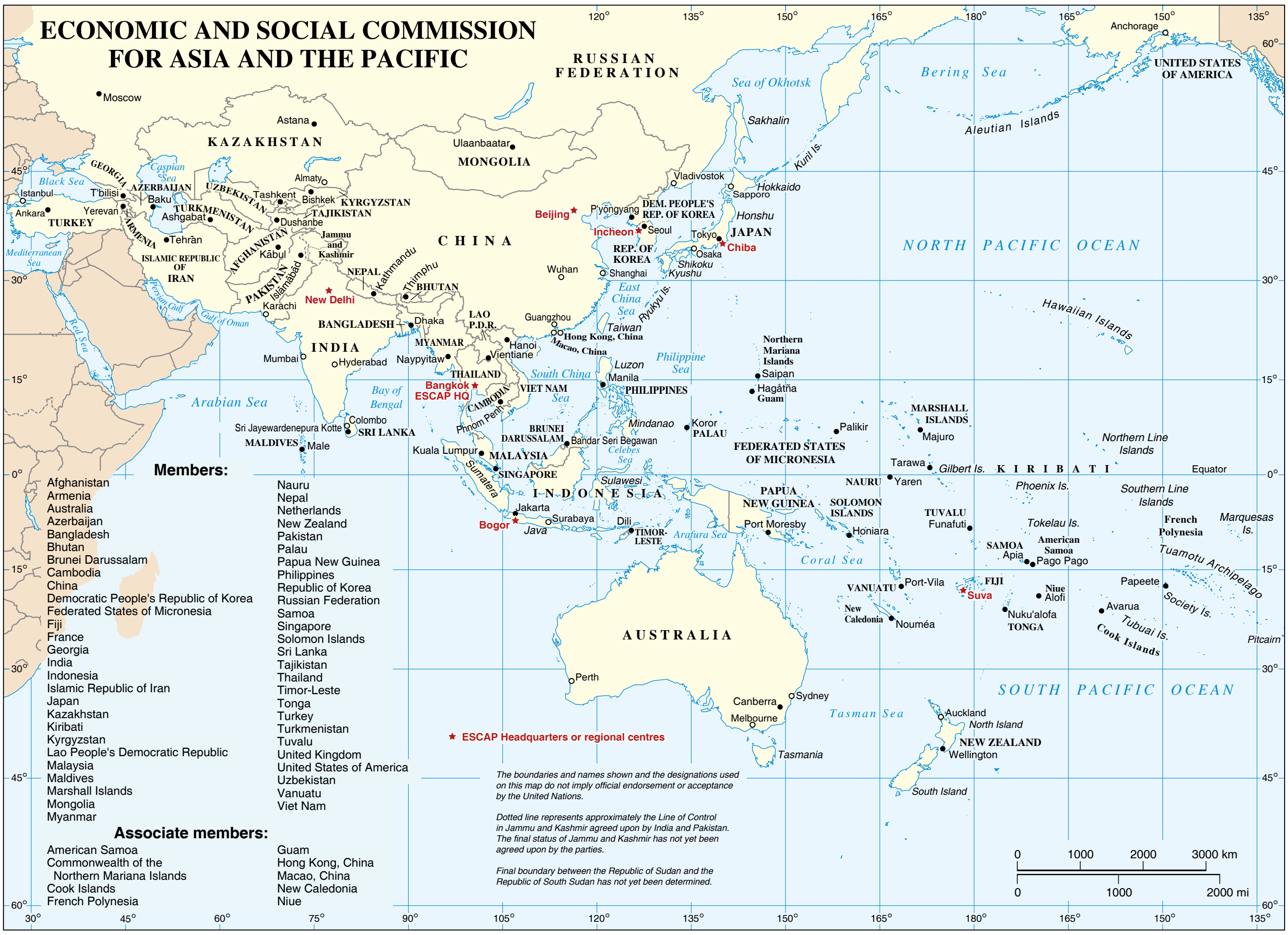
The Asia-Pacific region is extremely dynamic, undergoing rapid urbanization, economic growth, industrialization, and extensive agricultural development. Although these are desirable trends in many ways, they also represent drivers that are affecting the region's capacity to meet its socio-economic water development needs.

Demographics

Between 1987 and 2007, the region's population grew from just under 3 billion to about 4 billion people (UNEP, 2007). Average population density, at 111 people per km², is the highest in the world (UNEP, 2011). The demographic transition is taking place in all countries, but at different times and at a different pace. Although fertility rates have declined steadily, population growth rates remain high in some areas. Food security is an important issue since about two-thirds of the world's hungry people live in Asia (APWF, 2009). Internal migration and urbanization are driving the rise in the number of megacities (ESCAP, 2011). The region has some of the world's fastest-growing cities and between 2010 and 2025 a predicted 700 million people were added to the growing numbers requiring municipal water services (ESCAP, 2010*a*).

MAP 7.3

UNESCAP Member States



Source: Economic and Social Commission for Asia and the Pacific, Map No. 3974 Rev. 17, November 2011. Department of Field Support, Cartographic Section, United Nations.

Note: The ESCAP Members States in the Asia-Pacific subregions are as follows.

North-East Asia: *China, Democratic People's Republic of Korea, Japan, Mongolia, Republic of Korea, Russian Federation.*

Central Asia and the Caucasus: *Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan.*

South-East Asia: *Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, Viet Nam.*

South and South-West Asia: *Afghanistan, Bangladesh, Bhutan, India, Islamic Republic of Iran, Maldives, Nepal, Pakistan, Sri Lanka, Turkey.*

The Pacific: *American Samoa, Australia, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, New Caledonia, New Zealand, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu.*

"Food security is an important issue since about two-thirds of the world's hungry people live in Asia."

Economic development

Since 2000, the Asia-Pacific's GDP growth rate has surpassed 5% (UNEP, 2007). Industrial activity, often shifting from other regions, continues to grow. It is accompanied by the intensive use of resources that exert considerable pressure on aquatic ecosystems, which continue to deteriorate. In late 2008, the global food, fuel and financial crisis pushed millions of people below the poverty line in the recession that followed, but by 2010, rapid growth resumed in China and India and in some other countries. In 2010, ESCAP noted that 'enhanced incomes facilitate investments in much-needed technological change, infrastructure and job creation; however, current economic growth patterns increase the stress on limited resources and competition for access to them' (ESCAP, 2010a, p. 3).

Agriculture consumes an average of about 80% of the region's renewable water resources, but it is faced with the challenge of increasing food production in degraded ecosystems (APWF, 2009). In addition, the irrigation sector is generally inefficient, and demand-management mechanisms are ineffective where they exist. Water quality also suffers from the impacts of industrial development, urbanization and agricultural intensification (APWF, 2007).

Water conflicts

Water competition has led to increased water conflicts in the region, particularly over the past two decades. Conflicts within countries have dominated since 1990, with more than 120,000 water-related disputes in China alone during this period.[5] Water management efforts and resources in India often focus on 'conflict management' between different states. Direct conflict most commonly arises at the local level, and is often based on the construction of an 'ill-thought-out' dam, ambiguous water withdrawal rights or deteriorating water quality.

The allocation of increasingly scarce water resources, however, is the principal cause of water conflicts, with the most important challenge in the region's socio-economic development being to balance different water uses and to manage their economic, social and environmental impacts. In water-stressed countries, there are competing demands for water for urban, industrial, agriculture and ecosystems upon which livelihoods depend. In addition, water disputes arise over inter-basin water transfers, which have environmental, social and financial challenges (ESCAP, 2010*a*).

7.3.2 Challenges, risks and uncertainties

Hotspots

The many threats to water resources in the Asia-Pacific region reveal a complex picture and raise many concerns. To better prioritise regional action, ESCAP has identified 'hotspots' where there are multiple challenges. The hotspots are countries, areas or ecosystems that have overlapping challenges such as poor access to water and sanitation, limited water availability, deteriorating water quality, and increased exposure to climate change and water-related disasters. In the summer of 2010, for example, approximately one-fifth of Pakistan was inundated, affecting more than 20 million people in the flooded areas along the length of the River Indus. Flooding also destroyed more than 1.6 million acres of crops (Guha-Sapir, et al., 2011). South-East Asian countries in particular are at a development crossroads (Figure 7.3). Although high economic growth rates provide finances for better water resources management, many current development priorities ignore the risks from natural disasters, climate change, and poor household water and sanitation access. For example, India is in danger of being ill-prepared for natural disasters and climate change, while unsustainable water-use patterns are evident in Pakistan and Uzbekistan. Basic access to sanitation remains a major concern for Bangladesh.

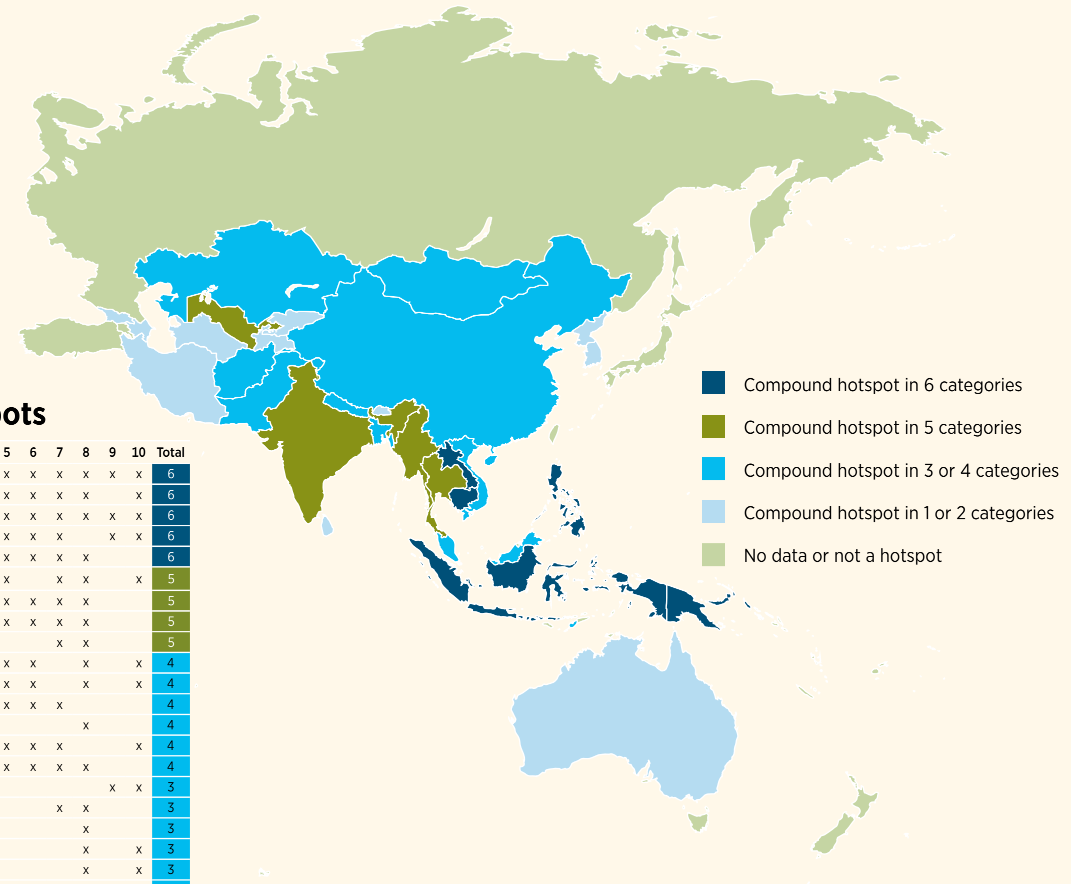
Areas of concern include some of Asia's major breadbaskets, such India's Punjab and the North China Plain. Water tables in these areas are falling by 2 m to 3 m a year, with serious impacts on agriculture and food security. Tropical deltas, where water productivity for food production is already low, are degrading and are at risk from sea-level rises. Food security is a challenge for many areas in the Asia-Pacific region – 65% of the world's undernourished people are concentrated in seven countries, five of which are in the Asia-Pacific region: India, Pakistan, China, Bangladesh and Indonesia (APWF, 2009).

Both high and low water-user groups are at risk of water scarcity because water endowment alone does not guarantee a sustainable water supply to support socio-economic development. Water scarcity can occur even in countries with rich renewable resources if it is not properly conserved, used and distributed among households, farms, industry and the environment (ESCAP, 2010*a*).

The ecological carrying capacity of the Asia-Pacific region is also affected by deteriorating water quality, with even relatively water-rich countries (such as Malaysia, Indonesia, Bhutan and Papua New Guinea) facing urban water supply and quality constraints. Domestic sewage is a particular concern because it affects ecosystems near densely populated areas. Approximately 150 to 250 million m^3 per day of untreated wastewater from urban areas is discharged

FIGURE 7.3

Asia-Pacific water hotspots



Compound hotspots

	1	2	3	4	5	6	7	8	9	10	Total
Cambodia					x	x	x	x	x	x	6
Indonesia			x		x	x	x	x		x	6
Lao PDR					x	x	x	x	x	x	6
Papua New Guinea				x	x	x	x		x	x	6
Philippines	x		x		x	x	x	x			6
India	x				x		x	x		x	5
Myanmar				x	x	x	x	x			5
Thailand			x		x	x	x	x			5
Uzbekistan	x	x		x			x	x			5
Bangladesh					x	x		x		x	4
China					x	x		x		x	4
Malaysia			x		x	x	x				4
Pakistan	x	x	x					x			4
Timor-Leste					x	x	x			x	4
Viet Nam					x	x	x	x			4
Afghanistan	x								x	x	3
Kazakhstan				x			x	x			3
Maldives	x			x				x			3
Mongolia				x				x		x	3
Nepal				x				x		x	3
Pacific Islands						x		x		x	3
DPRK				x	x						2
Kyrgyzstan				x			x				2
Tajikistan				x			x				2
Turkmenistan				x			x				2
Australia							x				1
Azerbaijan				x							1
Bhutan				x							1
Georgia				x							1
Iran								x			1
Republic of Korea					x						1
Sri Lanka								x			1
Prevalence (countries affected)	6	2	5	14	15	13	17	19	4	12	

Legend

1 Increasing water scarcity threat
2 High water utilization
3 Deteriorating water quality
4 Poor water quality and low water endowment
5 Flood-prone countries
6 Cyclone-prone countries
7 Drought-prone countries
8 Elevated ecosystem/Climate change risk
9 Poor access to drinking water
10 Poor access to sanitation

Sources: ESCAP (2006, 2010a); Dilley, et al. (2005); FAO AQUASTAT database (accessed 2010).

into open water bodies or leached into the subsoil.[6] This has consequences ranging from poor human health and increased infant mortality, to widespread environmental degradation. Degraded watercourses in cities exist because of demands on land, a lack of proper sanitation, insufficient drainage, or simply a lack of appreciation of their economic, environmental and ecological values.

Access to drinking water and sanitation

There is unequal access to drinking water and sanitation services throughout the Asia-Pacific region. This includes stark contrasts between urban and rural areas, and between rich and poor households – with sanitation being the most striking disparity. Even if adequate access to water and sanitation systems is established, the built facilities must be financially sustainable, functional, reliable, affordable, responsive to needs, socially acceptable for both genders, and appropriate for children and adults. Many social programmes are providing sanitation facilities that may be incompatible with the needs of women, for example, including lack of segregated toilets in schools, which can directly affect how frequently girls attend school.

The proportion of the region's population that has access to an improved drinking water source increased from 73% to 88% between 1990 and 2008 – that's an increase of 1.2 billion people (ESCAP, 2010*a*). China and India together account for a 47% share of the 1.8 billion people globally who gained access to improved drinking water sources over this period. Since 1990, 510 million people in East Asia, 137 million in South Asia, and 115 million in South-East Asia gained access to piped water connections on their premises (WHO–UNICEF, 2010).

However, the situation regarding access to sanitation is much less encouraging. Of the 2.6 billion people who do not use improved sanitation facilities, 72% live in Asia (WHO–UNICEF, 2010). Rapid progress in improved sanitation occurred in North-East Asia, with a 12% increase in access between 1990 and 2008, and in South-East Asia, with a 22% increase. In contrast, the situation in South Asia and South-West Asia is a concern. Although the number of people with sanitation access doubled since 1990, the 2008 average coverage was still only 38%, with the number without access actually higher than in 2005. Some 64% of the world population that defecate in the open live in South Asia. This is despite the fact that the practice decreased most in this area, down from 66% in 1990 to 44% in 2008 (WHO–UNICEF, 2010). In India alone, 638 million people still defecate in the open.

Climate change and extreme events

The Asia-Pacific is the world's most vulnerable region with respect to natural disasters, which undermine economic development to varying degrees. Much economic growth is generated in coastal and flood-prone areas, which are especially vulnerable to typhoons and rainstorms. Increased climate variability and extreme weather conditions are expected to severely affect the region, with floods and droughts predicted to increase in both magnitude and frequency. Excluding those affected by tsunamis, an annual average of 20,451 people were killed by water-related disasters in the region between 2000 and 2009. The annual global average for the same period was 23,651 (CRED, 2009).

The Pacific's small island developing states (SIDS) are particularly vulnerable to environmental natural hazards such as tropical cyclones, typhoons and earthquakes turning into disasters. One major tsunami or tropical cyclone can negate years of development effort. Climate change will further exacerbate the vulnerability of SIDS (and other low-lying coastal areas) with anticipated sea-level rise and the risk of storm surge and beach erosion.

The structure of gender relations is part of the social and cultural context that shapes a community's ability to prepare for, cope with, and recover from disasters. For example, in many Pacific islands men are responsible for activities related to the ocean and women for land-based ones. These roles are reflected in the way they prepare for an approaching hazard – men secure the physical structures, such as canoes, and women secure the food and families. These different roles need to be taken into account when addressing risk reduction equitably (Herrmann et al., 2005).

These observations about risk and uncertainty raise the issue of the sustainability of water supply and sanitation systems. Achievements in providing basic infrastructure, for example, should not only be assessed against a one-time coverage target. It is also important to ensure that what is built is functional, reliable, affordable, responsive to needs, and financially sustainable. The available information, however, suggests a regression in achievements, with many systems in the region functioning ineffectively, mostly as a result of a limited capacity to manage these systems and poor financial management.

7.3.3 Response measures

Institutional, legal and planning responses

The Asia-Pacific region has increasingly applied integrated water resources management (IWRM) principles in policies, strategies, plans and legal frameworks for water resources management throughout the region. Their actual implementation 'on the ground' has proven complicated, however, because of the need to involve water stakeholders at all levels of governance and civil society, and to establish a culture of inclusive consultation processes.

Various efforts are being made in the Asia-Pacific region to facilitate a sustained flow of ecosystem services (see Box 2.2 in Section 2.5). Innovative policies to support payment for ecosystem services are being established, or are under consideration, with examples in Viet Nam, Indonesia, the Philippines and Sri Lanka. Promoting household water security, recognizing the need to adapt to climate change threats, and initiating a 'wastewater revolution' are proposed priorities for regional cooperation, and are fundamental to unblocking the developmental difficulties attributable to poor water resources management in many countries in the region. Some countries have introduced a specific policy to prioritize sanitation in their national development plans. Examples include Thailand's Rural Environmental Sanitation Programme, which has been incorporated into its national economic and social development plans over the last 40 years, and the Total Sanitation Campaigns introduced in West Bengal and other locations in South Asian countries (CSD, 2008).

The Asia-Pacific region is attempting to reverse unsustainable consumption and production patterns by embarking on a greener development path. China, for example, is currently among the world's top exporters of green technology. 'Green Growth' was adopted at the 5th Ministerial Conference on Environment and Development in Asia and the Pacific in March 2005. It is the key regional strategy for inclusive and sustainable development, has emerged as a promising approach for pursuing greener development goals (also see Chapter 1 and Chapter 4). If put into operation in water resources management, Green Growth has the potential to address the development dilemma of providing basic water and sanitation services to all and sustaining economic growth, while also ensuring environmental sustainability.

> "Governments need to facilitate the creation of market conditions for developing sustainable and eco-efficient water infrastructure for better provision of water services."

Infrastructure responses

Water infrastructure in the Asia-Pacific region is shifting from predominantly short-term benefit planning and development, to a more strategic and long-term benefit planning concept that also addresses ecological efficiency in economic development. Governments need to facilitate the creation of market conditions for developing sustainable and eco-efficient water infrastructure for better provision of water services. This goal is envisaged for the region in three different contexts. The first is as a component of eco-city development programmes for addressing urbanization challenges. Possible eco-efficient infrastructure solutions in this context include urban river rehabilitation, modular water treatment design, integrated storm-water management, decentralized wastewater treatment, and water re-use and recycling. The second context focuses on rural areas, where the distance from urban centres makes traditional infrastructure expensive and inefficient. Modern irrigation systems, decentralized drinking water and sanitation services, water reuse and recycling, and rainwater harvesting are some promising solutions in the rural context. The third context relates to the urgent need to clean the region's waterways through a 'wastewater revolution'.

Treating wastewater for re-use is an essential consideration. Centralized wastewater treatment typically requires a large area, substantial funding and technical knowledge for sustained operation and maintenance. In some places, current technology for small, compact wastewater treatment plants has improved, offering advantages over larger, centralized systems.

Water resources management in the Asia-Pacific region appears to be shifting from a supply-oriented approach to a more demand-management approach. Large savings in water, energy and financial resources are expected as a result of increased efficiency and reduced consumption in the region. Continuing challenges facing the demand-management approach include evaluation of availability and demand in watersheds, possible reallocation or storage expansion in existing reservoirs, balancing equity and efficiency in water use, inadequate legislative and institutional frameworks, and the rising financial burden of aging water infrastructures.

Although the implementation of demand-management measures has been uneven across the region, interest in improving water-use efficiency continues to grow. Household water security, Green Growth, wastewater concerns and adaptations to climate change are driving this interest. Singapore, for example, reduced its urban domestic water demands from 176 L per capita per day in 1994, to 157 L per capita per day in 2007 (Kiang, n.d.). Leak detection programmes in Bangkok and Manila have lowered estimated unaccounted-for water, allowing new infrastructure development to be postponed (WWAP, 2009, Chapter 9). Since 2008, Sydney Water in Australia has offered a dual reticulation service where houses in the Hoxton Park area are given two water supplies – one for drinking water, and the other a recycled supply for general use (Sydney Water, 2011).

7.4 Latin America and the Caribbean

There is a long tradition of water management in the countries of Latin America and the Caribbean (LAC) (see Map 7.4), but with marked contrasts in its effectiveness among both countries and sectors. Commonalities among the countries can be seen in the advances that have been made. However, these advances have not always had the same pace and have not yet resulted in universal increases in water use efficiency or in any overall improvement in the levels of water quality.

Nonetheless, there has been an increase in the contribution of water to social and economic development. Although isolated advances can be observed in water management institutions, various countries have undertaken ambitious water management reforms, perhaps most notably Brazil and Mexico, but also, for example, Argentina, Chile, Colombia and Peru.

The main issues in water management facing the countries of the region have not changed significantly in the recent past (see Box 7.11). There has been a widespread inability to establish institutions that are able to deal with water management issues under conditions of increasing scarcity and conflict. The reasons for this lack of improvement include weak management institutions, insufficient operational capacity, informality, absence of self-financing and consequent dependence on fluctuating political support, and lack of reliable information in most areas of water management, including on the resource itself and its uses, users and future needs.

Contrasts abound, however, and these are not only due to variations in climate and hydrology or to the scale at which water management must operate (Brazil has 100,000 times the area of Dominica, for example) but equally or more so are due to differences in the nature and effectiveness of institutional systems, dissimilarities in the distribution and demographic structure of the population, and sizeable variations in levels of income. Impressive advances have been made in some countries in specific water management activities; for example, the high level of development of urban water supply and sewerage services in Chile.

7.4.1 The driving forces and pressures on water resources

Water management in LAC has always had to confront not just drivers arising within the 'water box', but also external drivers affecting both water management and the resource itself. The more significant external drivers include economic events, such as changing domestic policies, international financial crises (such as that in 2008–2009) and political instability; more subtle changes are produced by external influences related to gradual economic and social change. Extreme climatic events, especially hurricanes in the Caribbean, have long had a negative influence on water management. Recently, new uncertainties related to global climate change have been added to this list.

MAP 7.4

UNECLAC Member States

Source: Economic and Social Commission for Latin America and the Caribbean, Map No. 3977 Rev. 4, May 2011. Department of Field Support, Cartographic Section, United Nations.
Note: For the purposes of this chapter, the following ECLAC members are not considered part of the LAC region: Canada, France, Italy, Netherlands, Portugal, Spain, United Kingdom and United States of America. In addition, for the purposes of the chapter, only Aruba, British Virgin Islands and Cayman Islands are considered associate members of ECLAC.

Demographic change

More than 8% of the world's population lives in LAC – some 581 million people – with half of them in Brazil and Mexico (UNEP, 2007). The region is going through a period of rapid demographic change. Following the great migration to the cities in the 1960s and 1970s, the main characteristic of the current demographic situation is a rapid decline in birth rates resulting in a slowing in the rate of population growth – currently 1.3% for the region as a whole, which is expected to fall to less than 0.5% by 2050. If current trends continue, the population will even begin to fall absolutely in some countries, notably Cuba and Uruguay (CELADE, 2007). In contrast, annual population growth is still above 2% in several Central American countries. Increasing population will continue to contribute to rising demands for water throughout the region (UNEP, 2010*a*).

The decline in birth rates also means that, even if the total national population remains stable, many regions will lose population, especially those more rural and isolated. Smaller populations tend to mean reduced human and financial resources to support the operation and maintenance of infrastructure. This is particularly important where management responsibilities are decentralized. In the case of water supply and sewerage it can also mean that facilities may end up over-designed, hampering their operations. This can pose difficult questions in countries still expanding their water and sewerage infrastructure.

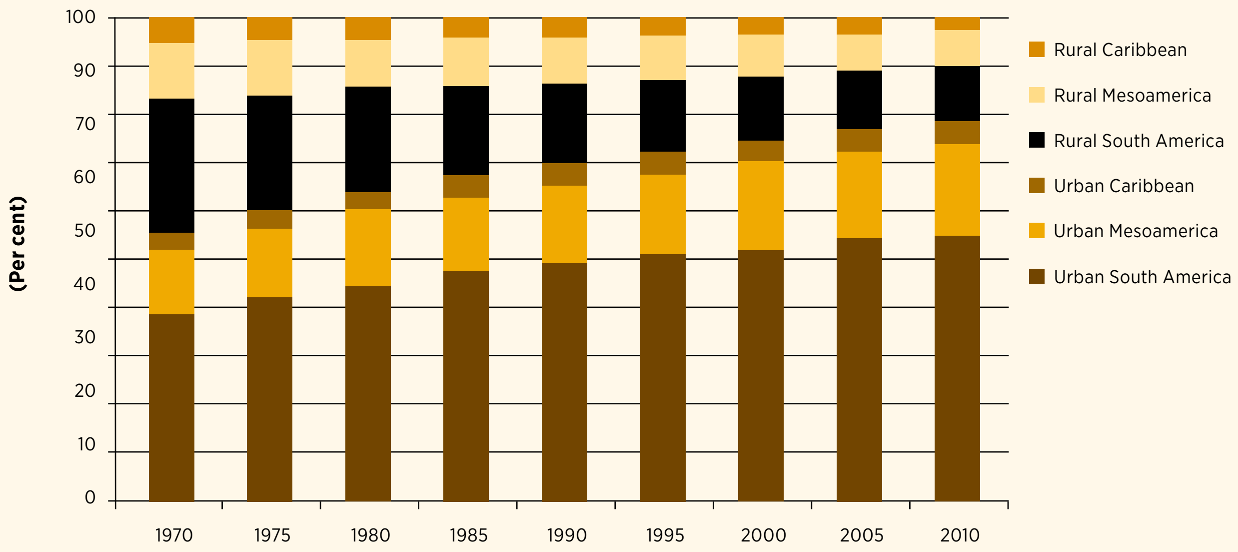
Latin America and the Caribbean is the world's most urbanized developing region; more than 80% of the population live in towns and cities (ECLAC, 2010*a*) (Figure 7.4). The urban population has tripled over the past 40 years and is expected to grow to 609 million by 2030. There are many cities with more than 1 million inhabitants, and in some countries, a high concentration in just one or two large cities (UNEP, 2010*a*). A recent trend has been the growth of population in medium-sized and small cities. There has also been recently an increasing settlement of what has historically been sparsely populated land, particularly in the Amazon and Orinoco river basins.

Economic development

Economic and social changes have obvious consequences for water use and the demands placed on the resource. The influence of these changes goes beyond the short-term effect of global financial crises, and beyond national economic unrest such as the so-called Mexico peso crisis of 1994 or the collapse of the Argentinean economy in 2001 (Klein and

FIGURE 7.4

Increase in urban populations between 1970 and 2010



Source: UNEP (2010a, p. 28, with statistics from the CEPAL STAT database [http://www.pnuma.org/geo/geoalc3/ing/graficosEn.php]).

Coutiño, 1996). Such events may hamper or interrupt the development of ongoing programmes, but they rarely have long-term effects. Far more important are the new demands for water arising from long-term changes in both LAC societies and the global economy. This is particularly the case with such apparently disparate changes in demands as that for tourism in the Caribbean and that for energy almost everywhere, both of which tend to be closely related to rising per capita income within the region and in the rest of the world (OECD, 2009). Sometimes these increasing demands for goods and services from water resource development produce conflicts which can pose serious problems for water management agencies. There are a number of examples, particularly regarding the construction of large hydroelectricity generating plants: the global controversy surrounding the decision of the Brazilian government to approve the construction of the Belo Monte Dam on the Xingu tributary of the Amazon is one such example, and the proposed construction of plants in the Río Baker in Chile is another.

As per capita incomes increase and the middle class grows, poverty levels have dropped in the region. In many countries, half the population has incomes 1.8 times above the poverty level, and in Uruguay, Chile and Costa Rica it is almost two-thirds (ECLAC, 2009). However, poverty remains an unresolved issue in all Latin America and most of the Caribbean. Although average poverty rates have fallen steadily over the past 20 years, an estimated 30% of the population of the region, or some 177 million people, still live in poverty, and 12% are considered extremely poor[7] (ECLAC, 2011). Decisions regarding water management and allocation have a role to play in poverty reduction through both the provision of public utility services and the creation of favourable conditions for economic development, as many economic activities, such as agriculture, mining and electricity generation, depend on water.

One result of the emergence of a larger middle class has been increasing demands to give more emphasis to the resolution of environmental conflicts. Examples include the cited opposition to dam construction, the acceptance of tariff increases to finance the ambitious programme of urban wastewater treatment in Chile (by the end of 2010 almost 87% of urban sewage was receiving treatment [SISS, 2011]), and the decontamination plan of the Matanza-Riachuelo basin in Argentina.

"One result of the emergence of a larger middle class has been increasing demands to give more emphasis to the resolution of environmental conflicts."

With the exceptions of Mexico and some of the small countries of Central America, the countries of the region base much of their economy on the export of natural resources. The global demand for these products has increased notably in recent years. Moreover, much of the production of these goods is financed by external capital and many of the facilities are foreign-owned. The result is that the major engine of economic growth in the region with heavy demands on the water resources is subject to many factors outside the direct control of the governments of the countries of the region.

For water management, this dependence on many natural resource-based activities is complicated by their location. The expansion of copper and gold mining in Chile and Peru has mainly occurred in arid areas and has led to competition for scarce water with both export agriculture and the needs of the indigenous population. Tourism demand has increased water stress on many Caribbean Islands (Box 7.9). Coffee production uses large quantities of water and its processing can seriously affect water quality. Similar issues arise with many other natural resources. One potential future demand for irrigation could come from the production of biofuels, although in Brazil, the only current significant producer, sugar cane production is rainfed and only 3.5% irrigation demand is for biofuel production (de Fraiture et al., 2008).

The uncertainty in the level and nature of demands of the global market and their changing nature have always complicated water management in LAC as local economies expand, contract and adjust according to the fluctuations of the global economy and so change the environment in which management decisions must be taken and policies applied.

Water availability and use

The annual average availability of water per capita in the region amounts to about 7,200 m^3. However, it is only 2,466 m^3 per person in the Caribbean. The Lesser Antilles, where rainwater is the primary water source, suffers the most acute water stress (UNEP, 2010*a*). In continental Latin America, overall demand on water resources remains low and spatially concentrated. Water withdrawals are estimated to be about 1% of available water, but they are much higher in the Caribbean – even in the mainland region,[8] they are equivalent to 14% of the available water (ECLAC, 2010*a*). Population concentrations, however, do not always coincide with plentiful water sources. Approximately one-third of the population in the region lives in arid and semi-arid areas. Northern Mexico, North-eastern Brazil, coastal Peru and northern Chile, among other areas, have great difficulty meeting their water needs. Population growth, expanded industrial activity, especially mining in Andean countries, and high irrigation demand have led to a ten-fold increase in total water extraction in the last century. Between 1990 and 2004, extraction grew by 76% (UNEP, 2010*a*). By the mid-2000s, it amounted to some 263 km^3 per year, with Mexico and Brazil together accounting for just over half that amount (UNEP, 2007).

BOX 7.9

Water management in Barbados

Barbados, with a population of about 290,000, is one of the world's most densely populated countries. It is a drought-prone island, almost entirely dependent on groundwater, and the available water supply is less than 390 m^3 per person per year. It is a country living under conditions of absolute water scarcity.

Universal water metering, via a variable tariff based on consumption, has been introduced, but the tariff was set too low. Some fairly successful water efficiency methods have been introduced but water consumption has increased with rising living standards. Tourism, which is very important to the economy of the island, is an especially large water user. Overall, water management has worked well although the water authority has suffered from poor management. Recently, Barbados received a loan from the Inter-American Development Bank to improve the water authority's efficiency, coastal zone management and climate change adaptation (IDB, 2009).

Source: BWA (2009).

7.4.2 Challenges, risks and uncertainties

The most significant risks and uncertainties facing water management in LAC are likely to stem from

- the impact of global economic events;
- continuing growth in domestic water use with increasing urbanization and rising living standards;
- the consequent need to improve the quality and extend the provision of water and sanitation services, especially to urban and peri-urban areas; and
- the impacts of climate change, especially on extreme events that affect water.

The effectiveness of improvements in water resources management, services and infrastructure, associated investments, and the relevant legislation and organization are very dependent on macroeconomic policies and the environment they create. 'Macroeconomic policy has a pervasive influence on the structure of incentives and performance in the entire water sector' (Donoso and Melo, 2004, p. 4). Unfavourable macroeconomic context erodes even the best water management policies, which has been evident in the countries of the region. For example, high rates of inflation can destroy attempts to develop effective charging systems for water use or to protect water quality. Similarly, in the long run, no water policies can be sufficient to compensate for the problems affecting sustainable water use, reflected in the lack of maintenance of infrastructure caused by economic stagnation or in underinvestment in expansion because of macroeconomic instability.

Conversely, successful macroeconomic policies leading to high rates of growth, as in Chile in the 1990s and in Argentina and Peru more recently, also impose challenges to water managers as new demands can emerge rapidly. Traditional polices often prove unable to resolve the problems created by the new economic environment and innovative institutional approaches can be required as water management becomes more complex. This can be especially critical in smaller countries where limited resources available, particularly those of professional and technical staff, meaning that institutional change can only come slowly.

Future demands and competition for water

As economic growth continues in the region and global demands for its mining, agricultural and energy resources increase, consequently so will the demand for water. For example, water use for energy can be expected to rise throughout the region in line with economic growth. Hydropower produces 53% of the region's electricity, and installed capacity grew by 7% between 2005 and 2008. Hydropower is expected to provide a significant proportion of the new energy demand (UNEP, 2010*a*). Balancing current and future water demands between competing uses (including ecosystems and their services) will become an issue. International demand has led to a 56% increase in mineral extraction in recent years, and despite the current slowdown in the global economy, it can be expected to continue to expand. Significant volumes of water are required for extraction, especially for precious metals, copper and nickel. Toxic waste and effluents from mining can run into water bodies, and this is one of the region's main sources of water pollution, as well as posing health and safety risks for local populations (Miranda and Sauer, 2010).

Agricultural demands will also increase. Around 14% of the region's cultivated area is under irrigation (FAO, 2011) and irrigation has expanded steadily since the 1960s. Given the intention of a number of countries in the region to play a major role in satisfying increased global demands for food and biofuels, irrigation will need to become more water-efficient.

On the whole, the region is doing well in providing improved water and sanitation for its urban populations, but is doing much less well for its rural populations. However, many cities still have substandard drinking water supplies and sewerage networks. Growing urban populations, especially in medium-sized cities, adds to the risk of not meeting water supply and sanitation needs. Expanding urban areas also not only require more water for domestic supply, but also are likely to expand onto floodplains and into catchment areas. These increasing demands can create significant risks for water management in dealing with local water scarcities and conflicts among water users (Box 7.10).

BOX 7.10

Competition for water in the Copiapo Valley

The Copiapo Valley in Northern Chile is an example of the conflicts that can arise from large-scale investments to serve global markets in areas where water is scarce. The region is the site of an increasing number of copper and other mines (which are even considering seawater desalination to meet their future demands), but it also produces large volumes of export crops, particularly table grapes – all in addition to the water needed for human supply which is also on the rise. The valley's surface waters have long been committed and there is increasing competition for groundwater among the fruit farmers. Wells are dug ever deeper and extraction rates exceed recharge. Chile's generally high level of governance of water user organizations and the operation of water markets have not prevented the problem. The trading of water rights has had little influence in relieving the water use conflicts in the valley. The form in which groundwater rights are defined, lack of controls and the impossibility to reach consensus on the measures to be adopted and to effectively implement them ('free-riding') have contributed to the current state of over-exploitation of water resources.

Sources: Personal communications in 2011 in Santiago, Chile with Michael Hantke-Domas and Humberto Peña.

Climate change and extreme events

Many parts of LAC have always been subject to a variety of extreme weather events such as floods and droughts, especially climate variability related to the El Niño-Southern Oscillation (ENSO) phenomenon. The frequency, duration and intensity of extreme weather events are expected to rise with climate change, increasing the need for risk management. Figure 7.5 shows that these events have already increased since the 1970s.

Flash floods and droughts affect the productivity of water ecosystems, living conditions and human welfare in both flood-prone areas and arid regions (IPCC, 2007). Urban flooding is a perennial problem in the region. For example, floods occur in most cities in the La Plata basin. The lack of storm sewers in many cities exacerbates the problem. In some densely populated cities, such as Caracas and Rio de Janeiro, where much housing is located on steep slopes, landslides worsen the impact of floods.

The region's glaciers are already receding because of climate change. Glacier retreat affects the water supply of an estimated 30 million people in the region (UNEP, 2010*a*). Some 60% of Quito's (Ecuador) and 30% of La Paz's (Bolivia) water comes from glaciers. Glaciers in Peru have lost 7 billion m^3 of water – a quantity that could supply Lima for 10 years. Droughts already occur regularly, and between 2000 and 2005 they caused serious economic losses and affected 1.23 million people (UNEP, 2010*a*).

The number of people living in already water-stressed watersheds in the absence of climate change is estimated at 22 million. The IPCC (2008) expects that with climate change, this number will increase to between 12 and 81 million in the 2020s and to between 79 and 178 million in the 2050s. Models also project an increase in the number of people at risk of malaria and dengue due to changes in the geographical limits of transmission.

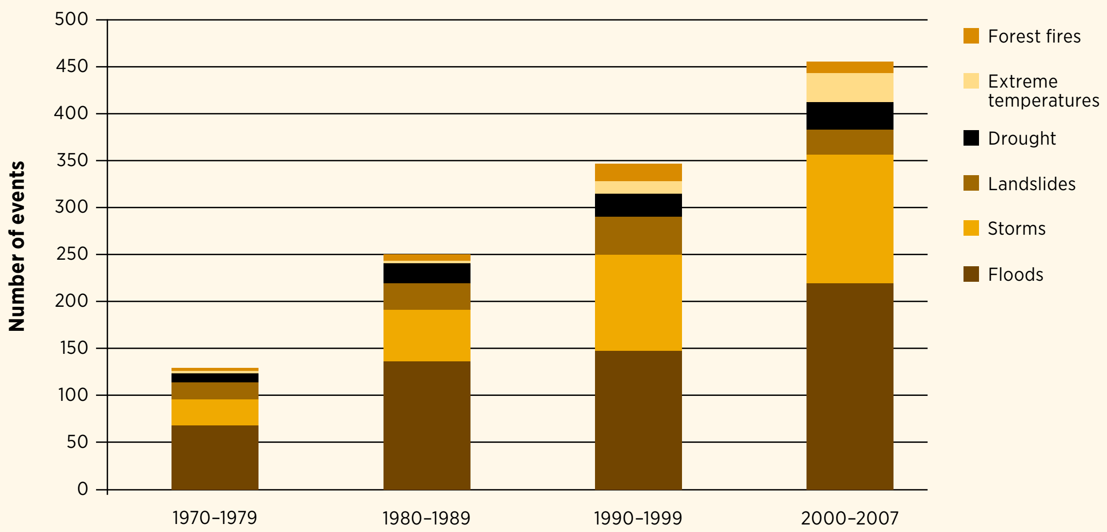
Climate change is likely to damage the important tourism industry of the Caribbean islands (UNEP, 2007). Sea level rise is also predicted to start affecting small island states, as well as continental coastal areas and river regimes, contributing to the deterioration in the quality, quantity and availability of water (ECLAC, 2010*b*). Climate change is expected to have adverse repercussions on the Pantanal, one of the world's largest wetlands, which stores water and regulates flows in the Paraguay River and its tributaries, helping mitigate droughts and floods (Roy, Barr and Venema, 2010).

The region's poorest countries in Central America, the Caribbean and the Andean region, with relatively weak water management capacities, will be at the highest risk from the effects of climate change and extreme events. The most serious example is Haiti, which is particularly vulnerable to extreme events because of deforestation, difficult topography, poverty and a lack of public infrastructure (ECLAC, 2010*a*).

Inadequate hydrological and meteorological observation networks hamper response to extreme events. On the positive side, lessons learned from adapting to the consequences of, for example, ENSO events in the region (e.g. in Peru) and the cycle of droughts and wet years in the drought polygon of North-eastern Brazil, have led to technological innovations that are applicable to water management in the face of climate change, and these have also led to increased human capacity (NOAA, n.d.). Extreme events would seem to bring only costs, as lives are lost and water and other infrastructure is damaged or destroyed. However, if water infrastructure resists serious damage or can be restored quickly, then the key role of water and

FIGURE 7.5

Frequency of hydrometeorological events, 1970–2007



Source: *UNEP (2010a, p. 40, with statistics from the CEPAL STAT database [http://www.pnuma.org/geo/geoalc3/ing/graficosEn.php]).*

water-related services is likely to win in public perception and will raise its influence within government.

Access to drinking water and sanitation

Over the past two decades there has been a slow but steady increase in most countries of LAC in the provision of both water supply and sanitation. By 2008, improved water supply was available to 97% of the urban population and 80% of the rural population (86% and 55% in the case of sanitation), more than meeting the MDGs at the regional level (WHO and UNICEF, 2010). These aggregate statistics, however, hide significant variations in the quality of the services. In many countries, the water supply and sanitation services are plagued by what has been defined as a vicious circle of low quality. Political interference, poor management and low tariffs all conspire to produce low quality services, and poor maintenance leads to interruptions in supply and low pressure, both of which can produce contamination within the system or the release of untreated wastewaters from sewage treatment plants (Corrales, 2004).

There remain large variations in access to services within countries. For example, in Central and Southern Mexico, Honduras and Nicaragua, there are many municipalities where less than 10% of the population have access to drinking water. In sanitation, the definition of what improved sanitation comprises is very general so that the published statistics provide little guidance to the real situation in many countries of the region (ECLAC, 2010*a*). It is estimated that almost 40 million people still lack even minimal access to secure water, and some 120 lack access to sanitation. In some areas, the cost of water is rising as a result of inefficient service provision, increasing demand and ever more intractable accessibility issues. Often, the poorest and most vulnerable people end up paying the most for water, as they depend on expensive but often poor-quality water purchased from tank trucks (UNEP, 2010*a*).

Undeniably, there has been improvement in most countries, but this in turn has brought to the fore other issues. It is estimated, for the region as a whole, that at best only 28% of sewage is treated before discharge, leading to serious contamination of water courses, including the sea, from both sewage outfalls and industrial discharges from urban areas (Lentini, 2008). The principal exception is Chile, where wastewater treatment will soon be universal (Box 7.11). Too often the political and technical complexity of introducing measures to control pollution has produced mixed results. For example, it is not clear that the introduction of charges for wastewater discharges in Colombia has been the determining factor in reducing water pollution.

There remain many problems to be resolved, including the recurring issue of under-financing water supply and sanitation services so that any gains in provision are negated, or at least reduced, by lack of maintenance, through the low levels of operating efficiency and the failure to adequately ensure sustainable financing. Lack of maintenance leads to large losses in piped water systems; for example, in Cuba the government estimates losses in distribution to amount to at least half of the water leaving the treatment plants (Business News America, 2010). Even in Chile, few systems have unaccounted for water under 30% (SISS, 2011).

7.4.3 Response measures

Institutional, legal and planning responses

The greatest challenge for water management in LAC is to continue to improve overall governance, a fact which governments are aware of (Comunidad Andina de Naciones, 2010). Responding to these challenges requires institutional arrangements for effectively

BOX 7.11

Investment in sanitary infrastructure in Chile

High levels of investment are a major factor in Chile's success in providing superior water and sanitation services to the urban population. Between 1999 and 2008, Chile invested more than US$2.8 billion in the water supply and sanitation sector, in addition to millions in controlling industrial pollution and building dedicated storm-drainage networks. An important impetus was the government decision to protect its export of agricultural products.

The main factors explaining the success of the reforms are (i) the creation of solid and high quality institutions with a long-term vision; (ii) discipline in criteria for investing fiscal resources; (iii) that the sector has always been managed responsibly and given high effective priority; (iv) that reforms were the result of a broad consensus built up at both the political and the professional level; and (v) the strategy of gradual change was governed by realistic and pragmatic judgment and a concern for ensuring overall coherence and keeping sight of the country's actual capacities.

Source: Valenzuela and Jouravlev (2007).

protecting public interest; defining and enforcing water use rights and discharge permits; setting standards, control and inspection mechanisms; and mobilizing significant financial resources.

If water management is to respond to the many needs for improvement, governments must establish a clear separation of policy and regulatory activities from day-to-day operations, improve incentives for efficiency, promote management training, adopt greater transparency in decision-making, and develop better systems for conflict resolution through a clear framework, increasing the participation of stakeholders in management decisions.

The magnitude of the challenge should not deter water managers and decision-makers from confronting them and making every effort to further strengthen water management within the social and economic sectors that depend upon it. A few countries have undertaken large-scale reforms in their water management institutions, notably Mexico, Chile and Brazil. In some instances, however, there remain problems with implementation, as in Brazil, where charges for bulk water and user fees are not being collected on a regular basis (Benjamín, Marques and Tinker, 2005). In other countries, institutions often do not have the capacity to succeed in undertaking major reform or consensus in this field continues to be elusive.

There have been a number of interesting experiences in the region over the past few decades in the establishment of water institutions outside sectoral ministries. For example, in Mexico water resources are managed by the National Water Commission (CONAGUA); and Brazil recently set up the National Water Agency (ANA) with the principal objective of overcoming traditional conflicts and limitations imposed by a system in which, until recently, water had been the responsibility of functional ministries. Other examples of institutions that are not directly linked to the functional aspects of water allocation and management include the Ministry of Environment, Housing and Territorial Development in Colombia; the Water Resources Authority in Jamaica; the Ministry of Environment and Natural Resources in Venezuela; and the General Water Directorate of the Ministry of Public Works in Chile. Reform of water laws is being discussed in most countries, but in practice, innovations are slow to materialize under real-world conditions (Solanes and Jouravlev, 2006). In recent years, new water legislation has been adopted in some countries (e.g. some provinces of Argentina, Nicaragua, Honduras, Peru, Uruguay and Venezuela) and several others have reformed their water laws (e.g. Chile and Mexico). Common tendencies include explicit adoption of the integrated water resource management paradigm, improvements in water governance, creation of water authorities and river basin organizations, and attention to public or water users participation, water resources planning and economic instruments. This, although in the early stages of implementation, is a major change in how some countries in the region manage their water resources.

Virtually all countries have reformed the water supply and sanitation sector, with emphasis on institutional separation of the functions of sectoral policy-making, economic regulation and service provision; extension of the decentralization process; an interest in private participation, although this trend was later reversed with the exit of large international private operators from most countries and renationalization of many services; formulation of specific regulatory frameworks; and the requirement that services should move towards being self-financing and that subsidy arrangements should be set up for low-income groups. Unfortunately, in many cases, reforms have failed to take account of the structural limitations of national economies as well as of sound principles in the area of public interest, economics of service provision and

"As for private sector participation, regional experience indicates that it is not the magic formula for addressing the multiple problems that affect the provision of water supply and sanitation services."

public utility regulation, and so have not met expectations. Some countries have recognized the right to water (Bolivia and Ecuador) or have set up mechanisms that improve the affordability of water services creating subsidies for the poor (Argentine, Chile and Colombia). As for private sector participation, regional experience indicates that it is not the magic formula for addressing the multiple problems that affect the provision of water supply and sanitation services.

The LAC region has 61 basins and 73 aquifers that cross national borders (UNESCO, 2010). Many countries have entered into transboundary water agreements, especially for hydropower development. Many political obstacles remain to wider cooperation in the management of international basins and there are some examples of potential conflict. Increasingly, bilateral and multilateral treaties do incorporate environmental concerns, including integrated water resources management or sustainability goals, but any application of such agreements is still in its infancy (Roy, Barr and Venema, 2010). One example of international cooperation at least in research is the studies undertaken on the Guarani aquifer (Box 7.12).

BOX 7.12

The Guarani Aquifer System (GAS) project: Managing transboundary groundwaters

The Guarani aquifer is shared by Argentina, Brazil, Paraguay and Uruguay. It extends over 1.2 million km^2 and some 15 million people live in the area overlying it. The four countries with the support of the World Bank cooperated in a study of current uses between 2003 and 2007. The aquifer is thought to contain about 40,000 km^3 of freshwater. Current exploitation is relatively modest, but demand is growing amid fears of over-pumping.

In August 2010, the presidents of the four countries signed an agreement for cooperation on extending knowledge of the aquifer and on identifying critical areas, which is noteworthy because agreements on transboundary aquifer systems are rare. The four countries have committed themselves generally to 'promote the conservation and environmental protection of the Guarani Aquifer System so as to ensure multiple, reasonable, sustainable, and equitable use of its water resources' (Article 4 of the Guarani Aquifer Agreement).

These initiatives show that it is possible to reach a basic consensus on what should be done so that proposals can be made to governments for reform in water management. It is a mistake to think that complex problems can be solved only by top-down initiatives or through the creation of new organizations and extrapolating from the experience of effective legislation and organizational structures that were achieved elsewhere only after a significant effort of coordination.

It is not sufficient to have reform proposals that are drafted only by experts: it is essential that any proposals have the widest public support if reform is to be placed on the political agenda. Water experts can inform the process towards building a consensus on the direction to be followed. If such a consensus does not exist, no true climate of confidence can be created for change and any proposed reform, or even adopted legislation, will never produce results. The challenge is to open water management to society as a whole. In doing so the water sector can build on its previous achievements to continue to make sustainable contributions to the betterment of society in all countries of the LAC region.

7.5 Arab and Western Asia region

The 22 countries of the Arab region, including the 14 members of the United Nations Economic and Social Commission for Western Asia (ESCWA) (see Map 7.5) include some of the most water scarce countries in the world. At least 12 of these countries suffer 'absolute' water scarcity because they have less than 500 m^3 of renewable water resources available per capita per year (see Chapter 33). Even the Arab countries that are relatively better endowed with water resources are often highly underdeveloped countries or countries in crisis. Several social, political and economic drivers have exacerbated this water scarcity, increasing the risk and uncertainty associated with water quantity and quality issues.

Rural development and food security policies further complicate regional water resources issues. Striving to address these regional challenges in a coordinated manner, Arab Governments established the Arab Ministerial Water Council (AMWC) under the auspices of the League of Arab States (LAS). The AMWC has responded to requests arising from the January 2009 Arab Economic and Social Summit in Kuwait to prepare an Arab strategy to assist the region in addressing current and future regional water scarcity and sustainable development challenges. The resulting

Arab Water Security Strategy (2010–2030) proposes measures to respond to these challenges, including implementing projects directed at water use efficiency, non-conventional water resources, climate change, integrated water resources management (IWRM), and water security. Risk reduction at the national level is being sought in developing water sector strategies, incorporating water issues into national development plans, pursuing institutional and legal reforms, and addressing uncertainties related to the management of shared water resources.

7.5.1 The driving forces and pressures on water resources

The key drivers affecting the Arab region's water resources are population growth and migration, growing consumption patterns, regional conflicts and governance constraints. These drivers have increased the pressures on already scarce freshwater resources, increasing the risks associated with water quantity and quality issues, the sustainable management of shared resources, and the uncertainties of policies promoting rural development and food security.

Demographics and socio-economic development

The Arab region has experienced a population increase of approximately 43% in over the past two decades. The total estimated population in 2010 was more than 359 million, and it is expected to reach 461 million by 2025 (ESCWA, 2009*b*). Over 55% of the population lives in urban areas, with rural to urban migration trends being observed in Egypt, Lebanon, Morocco,

MAP 7.5

UNESCWA Member States

Source: Economic and Social Commission for Western Asia, Map No. 3978 Rev. 11, December 2011. Department of Field Support, Cartographic Section, United Nations.
Note: For the purposes of this chapter, the countries of the Arab region are identified as those that are members of the League of Arab States: Algeria, Bahrain, Comoros, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Somalia, Sudan, Syrian Arab Republic, Tunisia, United Arab Emirates, Yemen.

the Syrian Arab Republic and Tunisia (UNDESA, 2007). This urban migration can be attributed mainly to reduced incomes and employment opportunities in the agricultural sector, combined with a burgeoning youth demographic. Arab governments have tried to slow this trend with rural livelihood policies that link agricultural production and rural development, even though this link resulted in a skewed allocation of scarce water resources to the agricultural sector throughout much of the region. Urban area water demands have also increased because of migration associated with economic development, and influxes of people displaced by regional conflicts. In addition to being concentrated along coastlines, urbanization is promoting settlement in reclaimed deserts, along expanded coastlines and urban peripheries. This has increased public and private sector investment in non-conventional water resources, particularly desalination, to ensure adequate freshwater resources.

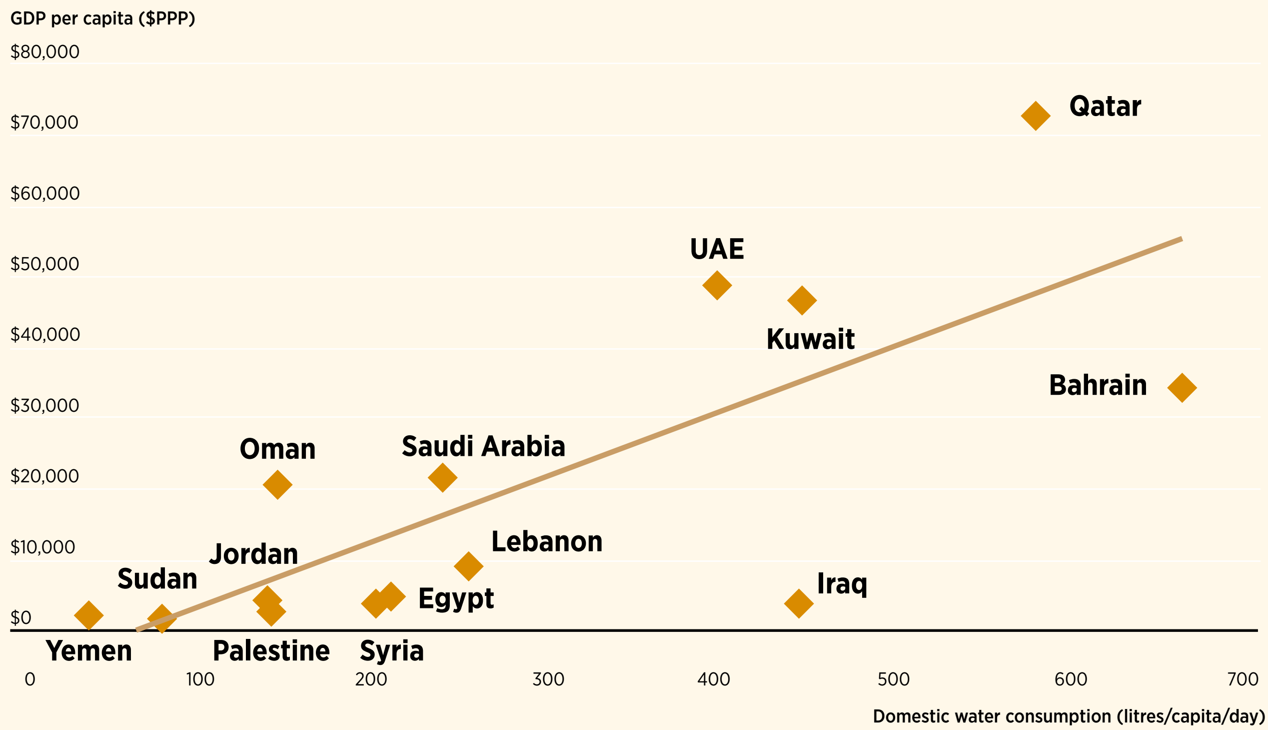
Water consumption in ESCWA member countries is largely tied to GDP (Figure 7.6), although this is mainly a consequence of their heavy reliance on desalination. Water consumption in other parts of the Arab region is largely tied to agricultural activities, which contribute only marginally to their GDP. Freshwater consumption in the Gulf Cooperation Council (GCC) countries continues to increase as a result of high incomes, comfortable lifestyles, real-estate development, the availability of energy for desalination, and growth in the tourism industry. In contrast, regional agricultural water consumption is characterized by low productivity, and has been significantly affected by droughts in recent years.

Regional conflicts and displaced persons

Cyclical conflict has characterized the Arab region for decades, generating large numbers of internally displaced persons. It has also caused increased regional migration and has strained water resources and services in areas receiving the displaced populations. The ESCWA region contains 36% of the world's displaced persons (ESCWA 2009*d*). Examples include 2 million Iraqi refugees in Jordan and Syria, Somalis in Yemen, Palestinians in refugee camps, and migrant workers and Libyans fleeing Libya for Egypt and Tunisia during the uprising which led to the regime change. Violent conflicts have destroyed water infrastructure at different times in Beirut, Kuwait and Lebanon, necessitating

FIGURE 7.6

Domestic water consumption relative to GDP per capita in the UNESCWA region



Source: ESCWA (2009c, p. 7).

the rehabilitation of damaged systems, instead of expanding water delivery.

The management of freshwater resources is further complicated by the fact that many major rivers in the Region are transboundary. The rivers in this category include the Tigris, the Euphrates, the Orontes (or Ali-Assi), the Jordan (including the Yarmouk), the Nile and the Senegal. Lake Chad too is transboundary, sometimes leading to political conflict between riparian neighbours. An estimated 66% of the Arab region's available surface freshwater originates outside the region. Subnational and local-level water conflicts can also exist between administrative districts, communities and tribes (Box 7.13).

At the same time, however, the 'Arab Spring' that started sweeping through the region in December 2010 can offer opportunities to revisit water governance structures and facilitate greater consultation at the community level. Soon after the respective regime changes, government officials in Tunisia and Egypt, for example, engaged with the issue, fostering greater public participation at the local level in planning and decision-making for the water sector.

BOX 7.13

Water conflicts in Yemen

Sana'a and Taiz in Yemen suffer from acute water scarcity – access to water has become a survival issue, and a cause of conflict. Some researchers believe that between 70% and 80% of the country's rural conflicts are about water. The situation is affected by a growing population, poor water management, illegal well drilling, a lack of law enforcement, a dependence on secure energy to deliver water, competition for water between urban and rural users, an influx of Somali refugees to Yemen, and unsustainable water allocations involving water use for agriculture, including qat (a mild narcotic plant popular in the area and which requires five times as much water as, for example, grapes).

Exacerbating the conflict is the fact that Yemen is one of the world's most water-scarce countries, with an annual per capita water availability of only 125 m^3, compared to the global average of 2,500 m^3. With their current usage rates, experts predict Sana's wells will run dry by 2015 (Kasinof, 2009).

7.5.2 Challenges, risks and uncertainties

Water scarcity

Nearly all Arab countries suffer from water scarcity, with water consumption in the Arab region significantly exceeding total renewable water supplies. Nearly all Arab countries can be characterized as water-scarce, while those formally endowed with rich water resources have seen their total annual per capita share of renewable water resources drop by half over the past four decades as their populations increase (Figure 7.7). This declining trend presents the most significant challenge to the water sector in the Arab region.

Egypt, Iraq, Jordan, Lebanon and Sudan derive 70% of their freshwater from perennial rivers. Surface water is the primary source in Oman, Saudi Arabia, the Syrian Arab Republic, the United Arab Emirates (UAE) and Yemen. These countries also have intermittent rivers (*wadis*) whose seasonal floods might be used to recharge aquifers. Other Arab countries obtain at least one-third of their total conventional water supply from groundwater, the extraction of which has increased to the extent that it threatens the sustainability of many national and shared aquifers, thereby increasing the risk of conflict.

The region's non-renewable shared aquifers, or 'fossil' aquifers that are being increasingly exploited include the Nubian Sandstone Aquifer, shared by Chad, Egypt and Libya; the North-Western Sahara Aquifer System shared by Algeria, Libya and Tunisia; and the Basalt Aquifer underlying Jordan and Saudi Arabia.

Water quality

The degree to which governments consider water quality a problem depends on differences in freshwater regimes and water scarcity conditions. Saltwater intrusion from over-pumping groundwater makes a major challenge of managing coastal aquifers, such as those along Egypt's northern coast, those along Lebanon's coast, those in the Gaza Strip, and the aquifers around several eastern Arabian Gulf coastal cities.

Expected rises in sea level will further increase stresses on coastal aquifers and river outlets, including the Nile Delta and at the Shatt Al-Arab. Pesticides and fertilizers from agricultural runoff, post-harvest processes, garment production, and domestic sewage are also contaminating surface water and groundwater in many areas. Impacts include eutrophication and fish kills in Lebanon, declining fish stocks in Lake Tunis (Harbridge et al., 2007), and negative aquaculture effects in the Egyptian Delta, thereby increasing food security risks. Pollution from oil production is a problem in some areas, although this is associated primarily with marine ecosystems. Rapid population growth in the Arab region, combined with migration pressures, inadequate urban planning and regulation enforcement, and large numbers of people living close to, or at, the poverty line, exacerbate the difficulties in protecting municipal water sources from contamination. Bifurcated water governance structures at the inter-ministerial level, and overlapping jurisdictional mandates between ministries and municipalities further complicate the situation.

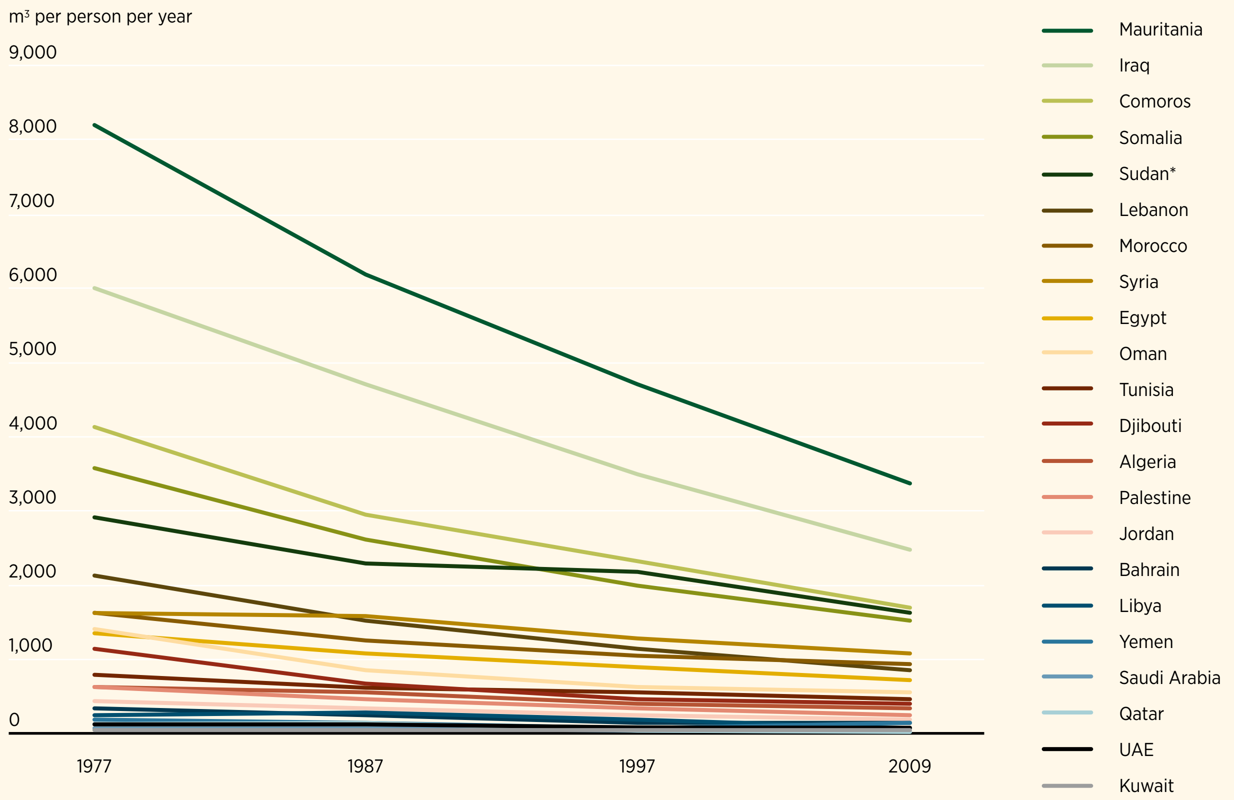
Food security

Agriculture is a primary source of water stress in the Arab region. It accounts for more than 70% of the total water demand in most ESCWA countries. In Iraq, Oman, the Syrian Arab Republic and Yemen, agriculture accounts for more than 90% of water use. Nevertheless, the region is unable to produce sufficient food to feed its populations, with ESCWA members importing 40% to 50% of their total cereal consumption. And the situation seems likely to worsen – studies predict climate change will cause a decline of as much as 25% in agricultural productivity in most countries in the region by 2080 (Cline, 2007).

Price increases in the global cereal market over the past few years, combined with unstable supply, also threaten food security, particularly since some countries are buying half or more of their cereal crops from abroad. The existing social structure also increases food supply vulnerability. In some countries, there is a concentration of wealth at the top, against the background where the majority of the population is clustered around or below the poverty line. Increased drought frequency, dependency on food imports and population growth leave the Arab region highly

FIGURE 7.7

Decline in renewable water resources in the Arab region per capita



*Note: *Area covering South Sudan and Sudan.*
Source: FAO AQUASTAT.

vulnerable to food insecurity. And in some countries, such as Egypt and Sudan, some are considering growing crops for more profitable commercial biofuels that will compete with food crops for the scarce water resources (ESCWA, 2009*e*).

As such, food security in the region has not been achieved at the national or regional level through food self-sufficiency. Subsidies and guaranteed price supports were used initially in some countries (including Egypt, Jordan and Saudi Arabia) to encourage food production. Subsequent initiatives to promote cereal production included greater investment in irrigation networks, increasing the capacity of reservoirs, and more pumping of groundwater. Intra-regional agricultural trade was encouraged through the Greater Arab Free Trade Agreement. As a result, there has been a shift in Arab food self-sufficiency policies towards a broader concept of food security, with governments that have the available financial resources able to pursue alternative measures within the global marketplace to achieve their food needs. Still others are re-examining their development and trade policies.

For instance, some countries are acquiring long-term leases on land outside their borders for food production, thereby increasing their imports of virtual water as a means to increase food security in face of growing water scarcity. Agribusiness firms and investment funds are leading this trend. Such land deals have become both popular and significant, with nearly 2.5 million ha of approved land allocations being made in African countries since 2004 (excluding allocations of less than 1,000 ha [Cotula et al., 2009]), which includes investments made by Arab countries. Although some aspects of this are controversial, this action provides some Arab countries with a relatively stable food supply, while providing host countries with infrastructure investments and potential economic returns.

Climate change and extreme events

The Arab region is particularly sensitive to the effects of climate change, particularly because it already suffers from extreme climate variability and water scarcity. Small changes in climatic patterns can result in dramatic ground-level impacts. Although the impacts remain uncertain, the expected consequences of climate change include increased soil temperatures and aridity, shifts in seasonal rainfall patterns (already being experienced in some rainfed agricultural areas such as the Syrian Arab Republic and Tunisia), reduced groundwater recharge rates, more frequent extreme weather events, including floods and droughts, reduced snowfall and snow-melt in some mountainous regions, and increased sea levels and water salinity in coastal aquifers. Droughts have already occurred more frequently in Algeria, Morocco, Syrian Arab Republic, Somalia and Tunisia over the past 20 to 40 years.

Larger populations, higher standards of living, and the associated increase in demand for water have contributed to the region's vulnerability to drought (ESCWA, 2005). The drought cycle in Morocco, for example changed from an average of one year of drought in every five before 1990 to one year of drought in every two between 1990 and 2000 (Karrou, 2002). In 2011, the Horn of Africa experienced one of the worst droughts in decades. Drought vulnerability is particularly significant in Arab countries that depend significantly on rainfed agriculture as a major economic activity. Drought also contributes to increased land degradation and desertification. Vulnerability to floods in the region has also increased as a result of rapid, often haphazard development in high risk areas such as *wadis*. Lax building codes and weak regulation and enforcement have played a part too, resulting in buildings and infrastructure that is not equipped to withstand major flood events.

Data and information

Lack of consistent and credible water resources data and information is hindering informed decision-making in the Arab region. It also is preventing the development of coherent and cooperative policy frameworks for shared water resources management and for assessing changes and progress. Some efforts have been made to increase the water resources knowledge base in the Arab region, including inter-governmental processes related to statistical reporting at the regional and global levels. Other processes have been established through regional reporting mechanisms or as academic initiatives.

Nevertheless, the difficulty of narrowing the gaps in the knowledge base rests to a large degree with political sensitivities and the national security concerns that are sometimes tied to this information. The result is that a patchwork of information and data from different sources is being used by the research and professional community, while official data often remains a resource that's sometimes difficult to obtain from governmental institutions.

7.5.3 Response measures

Institutional, legal and planning responses

Recognizing the need for a common approach to improving water resources management and achieving sustainable development in the Arab Region, the AMWC adopted the Arab Water Security Strategy in the Arab Region to Meet the Challenges and Future Needs of Sustainable Development (2010–2030) in 2011. Among its components, the strategy identifies priorities for action at the regional level focusing on the following: (1) socio-economic development priorities (including access to water supply and sanitation, and water for agriculture), finance and investment, technology, non-conventional water resources and IWRM; (2) political priorities that include managing shared water resources and protecting Arab water rights; and (3) institutional priorities associated with capacity building, awareness raising, research, and participatory approaches that involve civil society.

Regional institutions and initiatives have also been launched in the Arab region to respond to these priorities. These include the Arab Ministerial Water Council, whose first ministerial session was hosted by Algeria in June 2009. The Ministerial Council is an inter-governmental council established within the framework of the League of Arab States. It is supported by an Executive Bureau, a Technical Scientific Advisory Committee and a Technical Secretariat. Another example is the Arab Countries Water Utilities Association (ACWUA), which focuses on dialogue and capacity-building for water supply and sanitation. These institutions, among others, coordinate several regional water initiatives in the Arab region focused on climate change, shared water resources, integrated water resources management, MDGs and so forth.

At the national level, different ministries and authorities in the Arab region have the responsibility of managing water resources and delivering water services. Although only a few joint committees or units exist to support shared water resources, efforts have been enacted or are underway to improve institutional and legal frameworks in the water sector, including an increased incorporation of issues previously limited to IWRM planning. Institutions for addressing various issues associated with these goals have been established in Morocco (Makboul, 2009), Egypt, Yemen, Jordan, Palestine and Lebanon. The range of the various mechanisms include decentralization, private-public partnerships, public utility performance indicators, the integration of water resources management into development planning, groundwater management, infrastructure management, and sanitation and water resources management.

To strengthen resilience and preparedness regarding food security, some Arab countries have sought to ensure food security through trade, investment and contractual arrangements with other countries. Long-term leasing of agricultural lands in other countries has emerged as a tool for overcoming domestic agricultural production problems arising from water, land, energy and technological constraints, resulting in reduced food security risk. The host countries, in turn, can secure investments over an agreed time horizon allowing for the development of transport, water and energy infrastructure in the leased areas, as well as enhanced primary and secondary agro-industries. Areas targeted by the Arab region for future investment include Egypt, Sudan, Turkey, Ethiopia, Philippines and Brazil. The private sector and private investment firms also are involved. Putting such efforts into operation, however, has proven controversial, especially where indigenous communities and

> "To strengthen resilience and preparedness regarding food security, some Arab countries have sought to ensure food security through trade, investment and contractual arrangements with other countries."

pastoralists have traditionally used the leased lands. Chapter 33 provides further details on this topic.

In efforts to increase resilience to climate change adaptation and improve disaster preparedness, the Arab Ministerial Declaration on Climate Change (2007) expressed commitment to focus more on climate change adaptation and mitigation. It was followed by the drafting of a climate change action plan in the region. At the same time, Arab countries have worked to assess the effects of climate change on natural water resources as a means of informing their national adaptation plans and communications to the Inter-Governmental Panel on Climate Change (IPCC). A unified assessment was launched by the League of Arab States (LAS) and UN organizations serving the region under the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region, being reported to the AMWC and the UN Regional Coordination Mechanism.

Risk and uncertainty related to climate change and extreme weather events have also facilitated national and regional efforts directed at reducing disaster risk, planning and preparedness. The Arab Strategy for Disaster Risk Reduction for 2010–2015, adopted in 2010 by the Council of Arab Ministers Responsible for the Environment (CAMRE) and supported by the UN International Strategy for Disaster Reduction (UNISDR) and regional partners, focuses on national disaster inventories and capacity-building directed at improving land use planning, regulatory frameworks, financing and access to user-friendly information and communications tools.

Infrastructure responses

All Arab countries have pursued supply-side approaches to address increasing water demands. This has included dam building, desalinisation and water reuse, reservoirs, and new technologies to improve the efficiency of traditional and non-conventional methods such as water harvesting. Although large dams can have important negative environmental and social impacts, they also help reduce the uncertainty and risk related to floods and climatic variability.

A number of Arab countries have increased their total dam capacity. Egypt is at the forefront of this with a capacity of at least 169 km^3 added since 2003. Total dam capacity in Iraq for water supply nearly tripled between 1990 and 2000, from 50.2 km^3 to 139.7 km^3, while the Syrian Arab Republic increased its capacity from 15.85 km^3 in 1994 to 19.65 km^3 in 2007. Dams have also worked to counter the damage associated with flood events. The Sinai and Aswan dams effectively stored water during the 2010 flood, for example, protecting Ne'ama Bay, Nuweiba'a and Dahab in Egypt from floods (Government of Egypt, 2010), while also raising the groundwater table and preventing coastal saltwater intrusion.

One other approach being used by Arab countries to address water-associated risk and uncertainty is better management of aquifer recharge, as a means of both countering saltwater intrusion into coastal aquifers (particularly along the Mediterranean and Arabian Gulf coastlines), and for storing excess desalination-produced water as a buffer for future water demands or desalination plant failures in the GCC countries.

Arabian Gulf countries rely heavily on desalination for freshwater resources. Saudi Arabia currently has the world's greatest desalination capacity, followed by the UAE as the second largest producer. Jointly, they produce more than 30% of global freshwater production (ESCWA, 2009*c*). Desalination capacity also is supplying a growing share of freshwater in Algeria, Egypt, Iraq and Jordan. Co-generation, where power and desalinated water are produced at joint facilities is expanding in the Gulf region (Zawya, 2011), although this is not a cost-effective solution in energy-poor countries. Jordan, Morocco, Saudi Arabia and the UAE are advancing nuclear desalination prospects. Small household-level desalination units are being used by about 100,000 households in the Gaza Strip as a secondary drinking water source (World Bank, 2009), although health problems arose when the filters were overused because replacements could not be found.

The reuse of treated wastewater currently accounts for about 15% to 35% of total water resources produced from non-conventional sources in Egypt, Iraq, Saudi Arabia, the Syrian Arab Republic, and the UAE. Rainwater harvesting has expanded in the Arab region, and water harvesting through forest condensation is being increasingly considered. Other innovative approaches include fog harvesting and cloud seeding. Advanced remote sensing techniques (Shaban, 2009) have facilitated the identification of underwater springs in the region, although this approach could cause territorial disputes over shared sea and submarine resources. The Arab and Western Asia Regional Report provides further details on non-conventional water sources in the Arab region.

In the face of inherent water scarcity, coupled with rising populations and water use, demand-side management is another strategy to address the risks associated with water scarcity in the region. These actions include reducing water consumption, increasing water use efficiency, and adopting new types of regulations such as permits and tariffs for improved water services.

Despite these various risks and uncertainties, water is at the core of Arab culture and consciousness. Nevertheless, the Arab region faces continuing water scarcity, population growth, food security, climate change, extreme weather events, and existing and potential new conflicts over shared water resources. These factors, individually and collectively, will continue to influence the ability of Arab countries to manage the region's surface water and groundwater resources.

7.6 Regional–global links: Impacts and challenges

7.6.1 Linking the regional to the global

On a global scale, human activity, climate variability and other external pressures have taken their toll on both the availability and the quality of water. They have also weakened the ability of aquatic ecosystems to perform essential functions which support sustainable development (UNEP, 2006*a*). Over the last two decades, there has been international recognition that there is a need for a more sustainable use of water resources.

As demonstrated in Chapter 9, the global picture is composed of a number of inter-related environmental, economic, political, technological and social drivers. In order to understand the complex relationship between regional water challenges and global water problems, it is necessary to examine how regional challenges are linked to global water problems. Water challenges do not occur in a vacuum – through a series of interconnected webs they affect diverse countries and communities in many ways. The negative effects of the environmental degradation of water supply and excessive water withdrawals are borne not just by the regions in which such activities occur – their impact can be felt worldwide. Yet international cooperation through trade and other means can help to alleviate local pressures in areas of water scarcity by focusing water intensive activities in areas of greater water abundance and sharing those benefits with regions that may not have the water resources necessary to meet all the basic needs of their increasing populations (see Chapter 1). This interconnectedness will be demonstrated in this section by examining regional threats and their global outcomes, by looking at the ways in which economic and trade policies have influenced regional water management, and by considering a number of governance challenges.

Commitments to address water scarcity and shortages are made at international level, but the gap between these international objectives and the reality on the ground seems more and more evident. This stresses the need for a regional focus. For instance, a variety of global instruments addressing water issues have been established over the last decade: the United Nations General Assembly and the Human Rights Council of the United Nations recognized in July and September 2010, respectively, the right to water and sanitation as a human right (see Section 1.2.4); the G8 endorsed the Evian Action Plan; the World Economic Forum endorsed the Water Initiative in 2010, which encourages public private partnerships to work towards for a more water secure world; and a host of other initiatives have also been set up, including the World Water Council and the World Water Forum.

However, on the ground, many countries are becoming more water insecure, disparity of access is increasing, and all too often water administrators lack operational capacities and are becoming less coordinated in their efforts to address the water issue. Throughout the world, billions of people live in countries that do not have the water resources to meet their basic needs. Because much of the expected population growth will occur in regions that are increasingly unable to grow their own food, there will be more pressure on neighbouring countries and other regions that are better endowed with land and water. This is likely to create a very particular dynamic of inter-regional dependency, and a fragile balance between the 'haves' and the 'have nots' will need to be maintained.

When looking at the very tangible example of transboundary basins, which provide the bulk of water resources for drinking, sanitation, agriculture and industry, one notes that only 40% of transboundary basins

> "Poorly regulated foreign investments in lands that could be otherwise used to feed local populations, could potentially have devastating consequences on the fragile state of food security at the national level."

actually have even one agreement in place to govern the way the basin is used and managed (De Stefano et al., 2010). This is particularly worrisome as Africa has been identified by the IPCC as one of the continents that is most vulnerable to water stress, and which has increasing levels of desertification (IPCC, 2007). Unless these issues are addressed at the regional level, global commitments simply cannot be fulfilled.

The case of large land acquisitions

When addressing regional issues it becomes clear that policies and actions implemented in one geographic area have repercussions in other places. For instance, in efforts to conserve their scarce water resources, a number of countries are investing in agriculture abroad (Box 7.14). There are three main sources of law that govern foreign investment in agriculture: domestic law, international investment contracts, and international investment agreements, or IIAs. The interplay between them determines the extent to which international law will prevail over domestic law in any given instance and provide additional rights and remedies to foreign investors. In developed states, the domestic law provides a broad base that protects domestic stakeholders and governments and sets obligations for all investors. When this is not the case, as in many developing states, a weak or incomplete domestic legal base on social, economic or environmental issues can allow international contracts and treaties to enjoy much more liberal rights and entitlements. This is particularly relevant to foreign investments in agriculture, where domestic land tenure rights, water rights, environmental management regimes relating to chemicals, labour law on farms and so on can be weak or absent (Mann and Smaller, 2010). Saudi Arabia, one of the Middle East's largest cereal growers announced it would cut cereal production by 12% a year to reduce the unsustainable use of groundwater. In order to protect its water and food security, the Saudi government issued incentives to Saudi corporations to lease large tracts of land in Africa for agricultural production. By investing in Africa to produce its staple crops, Saudi Arabia is saving the equivalent of hundreds of millions of gallons of water per year and reducing the rate of depletion of its fossil aquifers. Saudi investors have already leased land in Sudan, Egypt, Ethiopia and Kenya. India is growing maize, sugarcane, lentils, and rice in Ethiopia, Kenya, Madagascar, Senegal and Mozambique to feed its domestic market, while European firms are seeking 3.9 million ha of African land to meet their 10% biofuel target by 2015 (Cotula et al., 2009).

This clearly demonstrates how policies enacted in one region have an impact on others through water. But there may be unforeseen negative consequences in many of the African states where these transactions are taking place. For instance, countries such as Ethiopia, where India has purchased 1 million ha of land, is one of the most food insecure countries in the world. Poorly regulated foreign investments in lands that could be otherwise used to feed local populations, could potentially have devastating consequences on the fragile state of food security at the national level. Other consequences include the displacement of populations, the dispossession of land, potential conflicts and instability as various groups are uprooted. There are also considerable negative environmental consequences as large-scale industrial agriculture requires fertilizers, pesticides, herbicides and large-scale transport, storage and distribution. Many of the states where such activities are taking place also have weak governance structures, with little legal protection for local communities and no benefit sharing mechanisms As a recent World Bank report notes, such agro-investments have deprived local people, particularly the most vulnerable, of their rights without providing appropriate compensation, while neglecting environmental and social safeguards (Deininger et al., 2010), and

BOX 7.14

Water dimensions of the surge in transnational land acquisitions

The current surge in large-scale transnational land acquisitions (also known as 'land grabs') results in fact from several drivers that have been accumulating for decades: the increase in population, coupled with changes in consumption habits, the stagnation of investment in and reduced aid to agriculture, reforms and structural adjustment programmes, and, more recently, the increase of land areas devoted to biofuel crops, often at the expense of food crops. Land degradation and water resource depletion have also constrained the ability of the agriculture sector to cope with the escalating demand for food. These drivers have increased the dependency of many developing countries on food imports and made small farmers – and, more generally, the rural and urban poor – more vulnerable than they had been to international food price fluctuations. More immediate triggers of land grabs were the food price hike in 2008, the oil price hikes during 2007–2008, and unfavourable weather conditions experienced in key cereal producing countries at around this time.

As there is currently no regulating or monitoring mechanism for these deals, the acreage of transnational land acquisitions is subject to great variability according to source and date, ranging from 15–20 million ha in 2009 (aggregate of the land deals listed in von Braun and Meinzen-Dick [2009]) to more than 70 million in 2012 Land Matrix Project data quoted in Anseeuw et al. [2012]). The database of the Matrix contains more than 2,000 deals, of which approximately half, totalling some 70 million ha, have been cross-checked. Africa consistently appears to be the prime target for these deals, with sub-Saharan Africa accounting for two-thirds of their acreage.

Some of the most active investors in large-scale transnational land acquisitions are oil-rich but food-insecure Gulf states, land-scarce, populous Asian countries, and developed countries. Non-state investors include Western food producing, processing and exporting companies – new actors attracted by biofuel demand and opportunities related to investment funds.

While the drivers behind land acquisitions have been discussed at length in the recent literature, the importance of access to water (in particular for irrigation) in driving the transnational search for land has not received adequate attention.

For China and India, water scarcity constrains the possibilities of responding to the growing food demand and therefore food security challenges through increasing domestic agricultural production, so alternatives must be explored. The land available for agriculture is also closing in these countries. Because of rapidly depleting fossil groundwater resources, Saudi Arabia had to reduce wheat production, leading to resumption of wheat imports in 2007 (Cotula et al., 2009; Smaller and Mann, 2009; Woertz, 2009); at around the same time (in 2008), an agricultural fund was established to promote agriculture investment abroad (Smaller and Mann, 2009).

Because of the growing unreliability of rainfed agriculture and growing freshwater scarcity, investors' crops often need irrigation, so a secure supply of water is a key aspect of the decision whether or not to invest. Agriculture trade specialists have long recognized the notion of trade in virtual water. Today, investment in water rights in foreign states through the purchase or lease of land with associated water rights and access is a critical motivation and part of the new process of securing long-term farming investments.

Nevertheless, water is typically not explicitly mentioned in the disclosed land deals. In the few cases where water is referred to, the amount of permitted water withdrawals is not specified. Evans (2009) quotes the Chief Executive Officer of Nestlé as saying, 'with the land comes the right to withdraw the water linked to it, in most countries essentially a freebie that increasingly could be the most valuable part of the deal. And, because this water has no price, the investors can take it over virtually free.' The consequences of this trend is harmful for the rural poor when they are forced to compete for scarcer water with actors who are more financially powerful and technically better equipped. Potential inter-state tensions and conflicts, especially in transboundary basins, are also a cause for concern. The current pace of land acquisitions and the related concessions of water rights to investors carry great threats to transboundary cooperation in many river systems, such as the Nile, Niger and Senegal basins.

In this context, approaching lack of land access and tenure insecurity in isolation from water rights is anachronistic – traditional solutions confined to the land sector are in many settings no longer effective. Water and land have become key strategic resources, more interlinked than ever before, so an integrated management approach to respond to the challenges of these resources' degradation and depletion is likely to be more effective than considering them in isolation. It is also imperative that investors take into account the possible impacts of these projects from the early planning stages on and incorporate appropriate measures.

Source: Madiodio Niasse (International Land Coalition Secretariat), Praveen Jha (University of Delhi), Rudolph Cleveringa (IFAD) and Michael Taylor (International Land Coalition Secretariat).

proposes principles for responsible agro-investments for fostering mutual benefits from agricultural investments abroad.

Similarly, the People's Republic of China has invested heavily in land in Indonesia, Thailand, Malaysia, Mozambique and the Democratic Republic of Congo, among others, to fulfil its biofuel policy. By 2020 the Chinese government anticipates that 15% of China's transport energy needs will be met by biofuels. As part of a massive plan to reduce greenhouse gases, China will replace 12 million tons of oil with 2 million tons of biodiesel and 10 million tons of bioethanol each year (Kraus, 2009). Despite the positive goal of investing in 'green and clean' energy, China's interventions have succumbed to negative externalities such as deforestation, biodiversity threats caused by monocultures, increased food prices and decreased food stocks (the International Monetary Fund estimates that that the increased demand for biofuels accounted for 70% of increased maize prices and 40% of soya bean prices between 2006 and 2008). The interventions have also caused population displacement, as land is converted into plantations, and water scarcity because water is a major input for growing primary biofuel commodities (Kraus, 2009). The amount of water required for biofuel plantations could be particularly devastating to regions such as West Africa, where water is already scarce (UNCTAD XII, 2008). For example, 1 L of ethanol from sugarcane requires 18.4 L of water and 1.52 m^2 of land (Periera and Ortega, 2010).

7.6.2 Regional threats and global outcomes

Weather-induced regional natural disasters and global impacts

The impacts of natural disasters are being felt more deeply in most regions of the world (see Section 4.4 and Chapter 27). Of all the natural and anthropogenic adversities, water-related natural disasters are the most recurrent, and pose the most serious impediments to achieving human security and sustainable socio-economic development (Adikari andYoshitani, 2009).

The factors that are thought to have contributed to the more severe impacts of water-related disasters include natural pressures, such as climate variability; management pressures, such as the lack of appropriate organizational systems and inappropriate land management; and social pressures, such as an escalation of population and settlement in high-risk areas, particularly by vulnerable populations (Adikari and Yoshitani, 2009).

Droughts, in addition to causing decreased access to water for particular communities, have significantly affected agricultural production – which has contributed to soaring food prices and food shortages (Krugman, 2011). For example, the cost of wheat almost doubled between the summer of 2010 and the summer of 2011 as a result of a sharp decrease in world production. According to the US Department of Agriculture, the bulk of this drop in wheat production can be attributed to Russia and Central Asia, which experienced record drought and heat in the summer of 2010 (Krugman, 2010). Fires in Russia and the ensuing decision to temporarily halt wheat exports led to sharp and rapid price hikes around the world (Hernandez, 2010). Increasing the price of a commodity like wheat does not merely affect its by-products and related foodstuffs. These increases have other major socio-political impacts, and can lead to far-reaching consequences such as food riots and political instability.

For instance, in Egypt the price of wheat is now 30% higher than it was in 2010 (Biello, 2011). Egypt consumes a great deal of wheat and rising bread costs coupled with other socio-political issues, resulted in considerable political instability and civil unrest. The relationship between food prices and political unrest in Egypt did not go unnoticed by other Middle Eastern countries – Algeria, Jordan, Libya, Morocco, Saudi Arabia, Turkey, Qatar and Yemen have all been purchasing larger supplies of wheat on the world market to limit soaring prices. This clearly demonstrates the link between drought-based food shortages and larger socio-political impacts.

Similarly, floods can have devastating effects on safe water supplies and have global impacts that go far beyond the regional scope. Floods, as the IPCC has concluded, are projected to increase in magnitude as a result of global warming and its effect on the hydrological cycle (IPCC, 2007). These are predicted to affect crop yields and livestock beyond the impacts of mean climate change. The number of people vulnerable to flood disasters worldwide is expected to mushroom to two billion by 2050 as a result of climate change, deforestation, rising sea levels and population growth in flood-prone lands (Adikari and Yoshitani, 2009).

As was seen in the case of drought, the damage caused by floods has worldwide consequences. For instance, in the January 2011 floods in Australia, over 900,000 km^2 of Queensland was flooded. That the floods had devastating effects on the socio-economic structures of Australia was to be anticipated, but what was surprising was the effect they had on a number of emerging economies too. Queensland is the biggest hub for Australia's coal exports and produces 28% of the world's total traded coal. In particular, Australia produces metallurgical coal on which 70% of steel production worldwide is dependent. Japan, India, China, Taiwan and South Korea were all affected by water damage in Queensland because their economic growth is heavily reliant on coal. Such consequences are not restricted to merely economic output, they also have an impact on livelihoods and infrastructural development.

7.6.3 Conflict, competition and cooperation

Water shortages can cause conflicts of varying intensities and scales. Although conflicts may appear localized, they present challenges to the broader context of peace and security. The multifaceted effects of conflict, such as displacement, mass migration, disruption to livelihoods, social breakdown, violence, health risks and human casualties, all have ripple effects that are felt throughout the global context. Conflict over water resources can also turn into, or fuel, ethnic conflicts. Because ethnic conflict is most commonly fuelled by collective fears for the future (Lake and Rothchild, 1998), it is easy to see how water scarcity could play to such fears.

Water has never been the sole cause of a major war, but nation states as we know them have also never experienced the kind of water shortages that are anticipated. Although there may have not been an outright war over water, it has still, historically, caused sufficient violence and conflict within and among states to warrant attention (Postel and Wolf, 2001). Where water is scarce, it can be viewed and interpreted as a security threat (Gleick, 1993).

When examining the case of Pakistan and India for instance, it is clear that water can be a potentially divisive issue in a context where the two countries are otherwise pursuing cooperative talks and negotiations. For instance, in order to feed its booming growth, expanding population and soaring energy needs, India is building numerous multipurpose dams. Currently it is at various stages of executing 33 projects that are raising concerns in Pakistan. The most controversial project, the 330 megawatt dam on the Kinshanganga River has sparked a reaction in the Pakistan. Although studies indicate that no single dam along the waters regulated by the Indus Water Treaty can stop or reduce water supply to Pakistan, the cumulative effect of all the dams can give India the ability to limit water supply to Pakistan at crucial moments during growing season, according to the US Senate Committee on Foreign Relations in 2011. It is important to note however, that this Senate Committee Report is contested by Indian government officials.

In today's global security context, no region is truly immune to conflict or strife in another. Despite political tensions however, nations have managed to successfully cooperate on water. For instance, India and Pakistan, despite fighting wars in 1965 and 1971 and facing cross-border confrontation in 2001–2002, have managed to adhere to the water commitments embedded in the Indus Waters Treaty (1960). Thus, collaboration on water issues is possible, and offers potential for cooperation between states. There is also a long tradition of successful cooperation in the field of transboundary water resources in Latin America (Querol, 2002).

Economic and trade policy impacts on regional water management

Economic and trade policies play a crucial role in promoting the sustainable use of water resources. The question that arises is what sort of policies are best suited to ensuring sustainable outcomes at national, regional and global levels. There is a tendency towards protectionist policies that protect national or regional resources, particularly as water becomes scarcer and more valuable. Protectionism argues that use of economic instruments and the market mechanism risks having water resources diverted to regions that have more economic prowess, leaving the vulnerable further marginalized. However, enacting protectionist policies can also foster a climate of inequality where water-poor regions cannot afford products that have high water footprints.

Policy-makers have to be cognizant that neither the market-based nor the exclusive reliance on command-and-control approaches can be a 'one-size-fits-all' approach. After all, what may seem like a beneficial intervention in one place, may have unintended consequences in others, given the complexity of the links between countries and regions. As some theorists suggest, resource scarcity in one region can have significant indirect effects on the international community. For instance, it can encourage powerful groups to capture vulnerable resources and force marginal groups to migrate to ecologically sensitive areas. This can lead to regional power struggles and instability within the international community, which could possibly provide elements for broader intra-state and inter-state conflict (Homer-Dixon, 1994).

In Chile, the existence of secure property rights in water appears to have made a noticeable contribution to the growth in the value of agricultural production (Lee and Jouravlev, 1998). The introduction of water markets coincided with a major increase in agricultural production and productivity. The influence of water markets, however, cannot be fully separated from the effects of economic stability and other economic reforms, especially trade liberalization and secure land rights. Trading does appear, however, to have succeeded in reallocating – with little conflict – water rights to higher value uses such as export-oriented agriculture, urban water supply and mining (Donoso, 2003).

> "Countries have also subscribed to international processes to harmonize perspectives and approaches to particular uses of water. Despite this, one of the major challenges is that countries attach different valuation to water and do not approach the resource with a common understanding."

There are useful reasons for incorporating the positive aspects of the market-based mechanisms when considering water resources. For instance, one of the reasons for water resource depletion is that water has been generally undervalued as a resource. It is thus important to place a value on it. Whether earmarking it as a commodity is the best way to place a value on it, is subject to debate. However, whether through norms or values, water resources must be valued for their worth, otherwise the trend of degradation will ensue. As highlighted in the Millennium Ecosystem Assessment, the heterogeneous nature of water makes it neither a public good nor private good, and it should not be treated uni-dimensionally (MES, 2005).

When attempting to make choices about how to place value on water resources in particular regions (in order to contextualize trade and economic policy), it may be useful to couch decision-making within the rights-based approach that the UN has adopted (see Section 1.2.4 about water and sanitation as a human right). Despite varying trends on how to treat water resources in different regions, the rights-based approach can provide a baseline where the protection of water rights, particularly of the most vulnerable, underpins other enterprises, legislation and policies governing transactions.

7.6.4 Governance challenges

'Water governance refers to the range of political, social, economic and administrative systems that are in place to regulate development and management of water resources and provisions of water services at different levels' (GWP, 2003, p. 7). Although many initiatives have been established to address the weaknesses in water governance, there remains a large chasm between regional governance and global governance structures.

In many ways, national structures are unable to address regional water resources issues, some of which may have global impacts. Regional and global mechanisms intervene when local- or national-level structures are insufficient to address water problems. Countries have also subscribed to international processes to harmonize perspectives and approaches to particular uses of water. Despite this, one of the major challenges is that countries attach different valuation to water and do not approach the resource with a common understanding (Langridge, 2008) (see Chapter 10). There are therefore challenges involved in transposing a governance structure that works in one region to another region – and harmonizing water policy objectives remains an elusive goal. As water is so closely linked to society, economy and the environment, there are no simple or easy answers that would ensure proper governance irrespectively. Although governance may be expressed in different organizational systems and its formal content arranged differently (such as laws and institutional arrangements), designing the governance system for a society must consider the natural conditions, power structures, and needs that are specific to that society.

Because international governance is driven by national member states, it is not surprising that it is often fragmented. Yet positive examples exist where different elements of individual systems can be replicated. For instance, the USA, France and Australia have developed highly sophisticated and resilient regimes for integrated river basin management (Shah et al., 2001). Many developed countries address the natural variability in terms of supply-side infrastructure to assure reliable supply and reduce risks. Although developing countries may not be able to import these structures because of their differing realities (for instance supply-side solutions alone may not be adequate to address the ever increasing demands from demographic, economic and climatic pressures), these countries may replicate other aspects such as waste-water treatment and water recycling and may promote demand management measures to counter the challenges of inadequate supply (UN-Water, 2008). Chapter 14 highlights other such instances where various elements of differing systems can be adopted by water managers, and adapted to particular contexts.

The needs of particular constituencies have to be at the heart of any effective regional governance mechanism. Although what has worked in one region may not necessarily work as effectively in another – such as in the case of the 'user pays' principle, which was successfully enforced in Australia, but abandoned in the Solomon Islands where it was determined that it was not sustainably viable because of major differences in political structures, national priorities, living standards, technical capacities, financial and infrastructural growth and change management competency (Shah et al., 2001). But common aspects of different systems can be explored (see Chapter 14).

Despite the variations that may occur in regional governance frameworks, there are also commonalities. These could support the basis of effective structures, and would include:

- Improved technical systems for water management
- Strengthened local managers
- Efficient resource management at the local level
- Improved horizontal and vertical coordination between different levels of authorities
- Improved information and monitoring systems
- Consensus-building, especially in professional groups, enhanced public participation in knowledge management of water resources
- The promotion of both regional and international cooperation

These improvements may be administered and implemented in different ways, but could yield to strengthened governance structures across different regions.

One of the challenges of strengthening governance structures is financing – this applies at both the international and the national levels. The resources may simply not be available for giving an overhaul to inefficient or underdeveloped administrative systems. As water scarcity becomes a pressing issue, synergies will have to be sought in different sectors. Water will not only have to be addressed by sustainable development or poverty alleviation schemes, but will have to be integrated more substantially into international cooperation, diplomacy, security and migration efforts.

Water law and science cannot be discrete areas of research and expertise. They must be integrated into areas which may seem unrelated – areas such as education, urban planning and social development. Addressing water shortages in the future has to integrate new levels of cross-sectoral and cross-regional thinking and coordination and should include a long-term vision.

Notes

1 See http://www.who.int/about/regions/afro/en/index.html for the WHO's definition of northern Africa and sub-Saharan Africa (SSA). SSA excludes Algeria, Egypt, Libya, Morocco and Tunisia.

2 This situation is further complicated by the fact that minimum water levels are fixed to account for navigation.

3 The terms 'Asia and the Pacific' and 'ESCAP region' refer to the group of members and associate members of the Economic and Social Commission for Asia and the Pacific.

4 Calculation by ESCAP staff based on the Joint Monitoring Programme 2010 report, accessed on 10 May 2010 at http://www.wssinfo.org/datamining/introduction.html

5 For the purpose of this analysis, conflict is not limited to armed conflict, but includes all water-related disputes necessitating mediation. Whether violent or not, these disputes have threatened the stability of the socio-economic development process in the region.

6 Calculation by ESCAP based on data from UNEP (2002).

7 The UNEP figures are based on ECLAC (2009), which defines 'extremely poor' as unable to meet basic nutritional requirements, even if all money is spent on food.

8 Caribbean countries in Central America and South America: Suriname, Guyana, French Guiana and Belize.

References

Adikari, Y. and Yoshitani, J. 2009. *Global Trends in Water-Related Disasters: An Insight for Policy-makers.* An Insight report for the United Nations World Water Assessment Program side papers series. Paris, UNESCO Publishing.

Alcamo, J. et al. 2007. Europe. M.L. Parry et al. (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. New York, Cambridge University Press, pp. 541–80.

AMCOW (African Ministers' Council on Water). *A Snapshot of Drinking Water and Sanitation in Africa – 2010 Update: A Regional Perspective Based on New Data* from the WHO/UNICEF Joint Monitoring Programme for Water and Sanitation. Prepared for AMCOW as a contribution to Third Africa Water Week Addis Ababa, Ethiopia 22–26 November, 2010. http://www.childinfo.org/files/Africa_AMCOW_Snapshot_2010_English_final.pdf

American Rivers. n.d. American Rivers Home Page. http://www.americanrivers.org (accessed 28 March, 2011).

Anseeuw, W., Alden Wily, L., Cotula, L. and Taylor, M. 2012 (forthcoming). *Land Rights and the Rush for Land: Findings of the Global Commercial Pressures on Land Research Project.* Rome, International Land Coalition (ILC).

APWF (Asia Pacific Water Forum). 2009. *Regional Document: Asia Pacific.* 5th World Water Forum. http://www.apwf.org/archive/documents/ap_regional_document_final.pdf

––––. 2007. Policy brief for the 1st Asia Pacific Water Forum in Beppu, Japan. http://www.apwf.org/archive/documents/summit/Policy_Brief_2007_080124.pdf

BWA (Barbados Water Authority). 2009. InterAmerican Development Bank, IDB, confirms strong support for Barbados and announces new Country Strategy. Press release, 26 November. Water for Life, http://www.barbadoswater.net

Bates, B. C., Kundzewicz, Z. W., Wu, S. and Palutikof, J. P. (eds). 2008. *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change.* Geneva, IPCC Secretariat.

Benjamín, A. H., Marques, C. L. and Tinker, C. 2005.The Water Giant Awakes: An Overview of Water Law in Brazil. *Texas Law Review,* Vol. 83, No. 7 2185–244.

Biello, David. 2011 Are High Food Prices Fuelling the Revolution in Egypt? *Scientific American,* 1 February, 2011. http://blogs.scientificamerican.com/observations/2011/02/01/are-high-food-prices-fueling-revolution-in-egypt/

Boko, M. et al. Africa. 2007. M. L. Parry et al. (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge UK, Cambridge University Press, pp. 433–67.

von Braun, J. and Meinzen-Dick, R. 2009. *'Land Grabbing' by Foreign Investors in Developing Countries: Risks and Opportunities.* IFPRI Policy Brief 13 (April). Washington DC, International Food Policy Research Institute (IFPRI).

Brown, C. and Hansen, J. W. 2008. *Agricultural Water Management and Climate Risk.* Report to the Bill and Melinda Gates Foundation. International Research Institute for Climate and Society Technical Report No. 08-01, Palisades, New York, IRI. http://portal.iri.columbia.edu/portal/server.pt/gateway/PTARGS_0_5280_2210_0_0_18/IRI-Tech-Rep-08-01.pdf

Business News Americas. 2010. INRH to repair water network over 10–15 years – Cuba. 12 January http://www.bnamericas.com.

CEC (Commission for Environmental Cooperation). 2008. *The North American Mosaic: An Overview of Key Environmental Issues. Water Quantity and Use.* Montreal, Quebec, CEC Secretariat. http://www.cec.org/Storage/32/2366_SOE_WaterQuantity_en.pdf

CELADE (Latin American and Caribbean Demographic Centre). 2007. *Proyección de Población.* Observatorio Demográfico No. 3, LC7G.2348-P. Santiago, CELADE.

Chile, Dirección General de Aguas. 2008. Ministro Bitar anuncia 99 por ciento de tratamiento de aguas servidas al bicentenario. http://www.dga.cl/index2.php?option=content&do_pdf=1&id=1306

Cline, W. 2007. *Global Warming and Agriculture: Impact Estimates by Country.* Washington DC, Center for Global Development and Peterson Institute for International Economics.

Comunidad Andina de Naciones. 2010. *El Agua de los Andes: un recurso clave para el desarrollo e integraciòn de la region.* Lima, Secretaría General de la Comunidad Andina. http://www.comunidadandina.org/public/libro_120.htm

Corrales, M. E. 2004. Gobernabilidad de los servicios de agua potable y saneamiento en América Latina. *Rega*, Vol. 1, No. 1, pp. 47–58.

Cotula, L., Vermeulen, S., Leonard, R. and Keeley, J. 2009. *Land Grab or Development Opportunity? Agricultural Investment and International Land Deals in Africa.* London/Rome, IIED/FAO/IFAD.

CRED (Center for Research on the Epidemiology of Disasters) 2009. EM-DAT: *The International Disaster Database.* Brussels, CRED. http://www.emdat.be

CSD (United Nations Commission on Sustainable Development). 2008. *Water and Sanitation: Progress on the Implementation of the decisions of the Commission at its 13th session.* Prepared for CSD, 16th session held in New York, 5–6 May, 2008.

Deininger, K. et al. 2010. *Rising Global Interest in Farmland: Can it Yield Sustainable and Equitable Benefits?* Washington DC, The World Bank. http://siteresources.worldbank.org/INTARD/Resources/ESW_Sept7_final_final.pdf

De Stefano, L., Duncan, J., Dinar, S. Stahl, K. and Wolf, A. 2010. *Mapping the Resilience of International River Basins to Future Climate Change-Induced Water Variability.* World Bank Water Sector Board Discussion Paper Series No. 15. Washington DC, The World Bank.

Dilley, M., Chen, R. S., Deichmann, U., Lerner-Lam, A. L., Arnold, M. et al. 2005. *Natural Disaster Hotspots: Global Risk Analysis.* Synthesis Report. Washington DC, The World Bank. http://sedac.ciesin.columbia.edu/hazards/hotspots/synthesisreport.pdf

Donoso, G. 2003. *Mercados de agua: estudio de caso del Código de Aguas de Chile de 1981.* Santiago, Pontificia Universidad Católica de Chile.

Donoso, G. and Melo, O. 2004. *Water Institutional Reform: Its Relationship with the Institutional and Macroeconomic Environment.* Santiago, Pontificia Universidad Católica de Chile.

EC (European Commission). 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October establishing a framework for the Community action in the field of water policy. Official Journal L327, 22/12/2000 P. 0001-0073.

––––. 2008. *Water Note 1: Joining Forces for Europe's Shared Waters: Coordination in International River Basin Districts.* Water Notes on the Implementation of the Water Framework Directive. http://ec.europa.eu/environment/water/participation/pdf/waternotes/water_note1_joining_forces.pdf

––––. 2009. The 1st River Basin Management Plans for 2009-2015. http://ec.europa.eu/environment/water/participation/map_mc/map.htm

ECLAC (United Nations Economic Commission for Latin America and the Caribbean). 2009. *Social Panorama.* Santiago, ECLAC.

––––. 2010*a*. *Millennium Development Goals, Advances in Environmentally Sustainable Development in Latin America and the Caribbean.* Santiago, ECLAC. http://www.un.org/regionalcommissions/MDGs/eclac_mdgs09.pdf

––––. 2010*b*. *Statistical Yearbook for Latin America and the Caribbean,* 2009. Santiago, ECLAC.

––––. 2011. *Social Panorama.* Santiago, ECLAC.

EEA (European Environment Agency). 2005. *Source Apprtionment and Phosphorus Inputs into the Aquatic Environment.* EEA Report No. 7. Copenhagen, EEA.

––––. 2007. *Europe's Environment: The Fourth Assessment.* State of the Environment Report. Copenhagen, EEA. http://www.eea.europa.eu/publications/state_of_environment_report_2007_1

––––. 2010. *The European Environment – State and Outlook 2010.* Denmark, EEA. http://www.eea.europa.eu/soer

EPA (The US Environmental Protection Agency). 2008. Home Page. http://www.epa.gov/roe/index.htm (Accessed 19 November 2010.)

ESCAP (United Nations Economic and Social Commission for Asia and the Pacific). 2006. *State of Environment in Asia and the Pacific 2005 Synthesis.* Bangkok, ESCAP. http://www.unescap.org/esd/environment/soe/2005/download/SOE%202005%20Synthesis.pdf

––––. 2010*a*. *Statistical Yearbook for Asia and the Pacific,* 2009. Bangkok, ESCAP.

––––. 2010*b* Preview: *Green Growth, Resources and Resilience: Environmental sustainability in Asia and the Pacific.* Bangkok, ESCAP. http://www.unescap.org/esd/environment/flagpubs/GGRAP/documents/Green%20Growth-16Sept%20(Final).pdf

––––. 2011. Population Dynamics: Social Development in Asia-Pacific. http://actionbias.com/issue/population-dynamics

ESCAP, ADB (Asian Development Bank) and UNDP (United Nations Development Programme). 2010. *Achieving the Millennium Development Goals in an Era of Global Uncertainty.* Asia-Pacific Regional Report. Bangkok, ESCAP, ADB and UNDP. http://content.undp.org/go/cms-service/stream/asset/?asset_id=2269033

ESCWA (United Nations Economic and Social Commission for Western Asia). 2005. *ESCWA Water Development Report 1: Vulnerability of the Region to Socio-Economic Drought.* E/ESCWA/SDPD/2005/9. New York, ESCWA. http://www.escwa.un.org/information/publications/edit/upload/sdpd-05-9-e.pdf

––––. 2009*a*. *Compendium of Environmental Statistics in the ESCWA Region, 2008–2009.* 2nd Issue. New York, ESCWA. http://www.escwa.un.org/information/pubaction.asp?PubID=653

––––. 2009*b*. *The Demographic Profile of the Arab Countries.* E/ESCWA/SDD/2009/Technical Paper9. New York, ESCWA. http://www.escwa.un.org/information/publications/edit/upload/sdd-09-TP9.pdf

----. 2009*c*. *ESCWA Water Development Report 3: Role of Desalination in Addressing Water Scarcity.* E/ESCWA/SDPD/2009/4, New York, ESCWA. http://www.escwa.un.org/information/publications/edit/upload/sdpd-09-4.pdf

----. 2009*d*. *Trends and Impacts in Conflict Settings: The Socio-Economic Impact of Conflict-Driven Displacement in the ESCWA Region.* Issue 1. E/ESCWA/ECRI/2009/2. New York, ESCWA. http://www.escwa.un.org/information/publications/edit/upload/ecri-09-2.pdf

----. 2009*e*. *Increasing the competitiveness of small and medium-sized enterprises through the use of environmentally sound technologies: Assessing the potential for the development of second-generation biofuels in the ESCWA region.* E/ESCWA/SDPD/2009/5. New York, ESCWA.

Evans, A. 2009. Managing scarcity: The institutional dimensions. *Global Dashboard,* 25 August.

FAO (Food and Agriculture Organization of the United Nations). 2005. *Irrigation in Africa in Figures: AQUASTAT Survey – 2005.* FAO Water Report No. 29, Rome, FAO. ftp://ftp.fao.org/agl/aglw/docs/wr29_eng.pdf

----. 2008. Mapping poverty, water and agriculture in sub-Saharan Africa. Faurès, J.-M. and Santini, G. (eds), *Water and the Rural Poor: Interventions for Improving Livelihoods in sub-Saharan Africa.* Rome, FAO. ftp://ftp.fao.org/docrep/fao/010/i0132e/i0132e03a.pdf

----. 2011. General Summary for the Countries of the Former Soviet Union. Rome, FAO. http://www.fao.org/nr/water/aquastat/regions/fussr/index5.stm (accessed March 31, 2011).

Field, C. B. et al. 2007. North America. M.L. Parry et al. (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. New York, Cambridge University Press, pp. 617–52.

Foster, V. and C. Briceño-Garmendia (eds). 2010. *Africa's Infrastructure: A Time for Transformation.* Africa Infrastructure Country Diagnostic (AICD). Washington DC, The World Bank. http://siteresources.worldbank.org/INTAFRICA/Resources/aicd_overview_english_no-embargo.pdf

Foster, S., Kemper, K., Garduño, H., Hirata, R. and Nanni, M. 2006. *The Guarani Aquifer Initiative for Transboundary Groundwater Management.* Washington DC, The World Bank.

de Fraiture, C., Giordano, M. and Liao, Y. 2008. Biofuels and implications for agricultural water use: Blue impacts of green energy. *Water Policy,* Vol. 10, Supplement 1, pp. 67–81.

Gleick, P. 1993. Water and conflict freshwater resources and international security. *International Security,* Vol. 18, No. 1, pp. 79–112.

Government of Egypt. 2010. Mubarak receives report on facing floods in future. *ReliefWeb,* 13 February. http://www.reliefweb.int/node/345133

Guarani Aquifer Agreement. 2010. International Water Law Project. http://www.internationalwaterlaw.org/documents/regionaldocs/Guarani_Aquifer_Agreement-English.pdf

Guha-Sapir, D. et al. 2011. *Annual Disaster Statistical Review 2010: The Numbers and Trends.* Brussels, CRED. http://www.undp.org.cu/crmi/docs/cred-annualdisstats2010-rt-2011-en.pdf http://www.globalwaterintel.com/archive/9/9/analysis/world-water-prices-rise-by-67.html.

GWP (Global Water Partnership). 2003. Effective Water Governance, Peter Rogers and Alan W. Hall, GWP Technical Committee Background Papers No. 7.

Harbridge, W. et al. 2007. Sedimentation in the Lake of Tunis: A lagoon strongly influenced by man. *Environmental Geology,* Vol. 1, No. 4, pp. 215–25.

Herrmann, T. M., Ronneberg, E., Brewster, M. and Dengo, M.. Social and economic aspects of disaster reduction, vulnerability and risk management in small island developing states. *Small Island Habitats,* pp. 231–33 http://www.sidsnet.org/docshare/other/20050126112910_Disaster_Reduction_and_Small_Islands.pdf

Hernandez, M. A., Robles, M. and Torero, M. 2010. *Fires in Russia, Wheat Production, and Volatile Markets: Reasons to Panic?* 2010 International Food Policy Research Institute, 6 August. http://www.ifpri.org/sites/default/files/wheat.pdf

Homer-Dixon, T. 1994. Environmental scarcities and violent conflict: Evidence from cases. *International Security,* Vol. 19, No. 1, pp. 5–40.

Hughes, D. 2008. Identification, estimation, quantification and incorporation of risk and uncertainty in water resources management tools in South Africa. *IWR Water Resource Assessment Uncertainty Analysis.* Project Inception Report. Grahamstown, South Africa, Rhodes University. http://www.ru.ac.za/static/institutes/iwr/uncertainty

ICPDR (International Commission for the Protection of the Danube River). 2007. *Issue Paper on Hydromorphological Alterations in the Danube River Basin.* IC/WD/265, document version, 12. Vienna, ICDPR. www.icpdr.org/icpdr-files/14717

IDB (Inter-American Development Bank). 2009. IDB confirms strong support for Barbados and announces new Country Strategy. Press Release, Washington DC, IDB, 26 November.

Indus Waters Treaty. 1960. http://siteresources.worldbank.org/SOUTHASIAEXT/Resources/223546-1171996340255/BaglliharSummary.pdf

IPCC (Intergovernmental Panel on Climate Change). 2007. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, Cambridge University Press. http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-intro.pdf

----. 2008. *Climate Change and Water.* IPCC Technical Paper IV. http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf

Karrou, M. 2002. *Climatic Change and Drought Mitigation: Case of Morocco,* INRA, Rabat, Morocco. Presented at the first CLIMAGRImed Workshop, FAO, Rome, 25–27 September. http://www.fao.org/sd/climagrimed/pdf/ws01_38.pdf

Kasinof, S. 2009. At heart of Yemen's conflicts: Water crisis. *The Christian Science Monitor,* 5 November. http://www.csmonitor.com/World/Middle-East/2009/1105/p06s13-wome.html

Kiang, T. T. n.d. Singapore's experience in water demand management. http://www.iwra.org/congress/2008/resource/authors/abs461_article.pdf

Klein, L. R. and Coutiño, A. 1996. The Mexican Financial Crisis of December 1994 and lessons to be learned. *Open Economics Review,* Vol. 7, pp. 501–510.

Kraus, M. 2009. *Fuelling New Problems: The Impact of China's Biodiesel Policies.* Asia Paper: Brussels Institute of Contemporary China Studies. Brussels, BICCS.

Krugman, P. 2011. Droughts, floods and food. *New York Times,* 9 February. http://www.nytimes.com/2011/02/07/opinion/07krugman.html

Lake, D. and Rothchild, D. (eds). 1998. The International Spread of Ethnic Conflict. Princeton, NJ and Chichester, UK, Princeton University Press.

Langridge, R. 2008. Developing global institutions for governing water. *Journal of International Affairs,* Vol. 61, No. 2.

Lee, T. and Jouravlev, A. 1998. *Prices, Property and Markets in Water Allocation.* LC/L.1097. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.eclac.cl/publicaciones/xml/4/4704/lcl1097i.pdf

Lentini, E. 2008. Servicios de agua potable y saneamiento: lecciones de experiencias relevantes. Document presented at the regional conference on *Políticas para servicios de agua potable y alcantarillado económicamente eficientes, ambientalmente sustentables y socialmente equitativos.* Economic Commission for Latin America and the Caribbean (ECLAC), Santiago, Chile, 22–24 September 2008.

Lloret, P. 2009. Water Protection Fund (FONAG). *Circular of the Network for Cooperation in Integrated Water Resource Management for Sustainable Development in Latin America and the Caribbean,* No. 29. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/drni/noticias/circulares/2/34862/Carta29in.pdf

Makboul, M., 2009. Loi 10-95 sur l'eau: Acquis et perspectives. UNESCO Country Office in Rabat, Cluster Office for the Maghreb, *L'Etat des Ressources en Eau au Maghreb en 2009,* Rabat, UNESCO, pp. 47–59.

Mann, H. and Smaller, C. 2010. Foreign land purchases for agriculture: What impact on sustainable development? *Sustainable Development Innovation Briefs,* Issue 8. http://www.un.org/esa/dsd/resources/res_pdfs/publications/ib/no8.pdf

MES (Millennium Ecosystem Assessment). 2005. *Ecosystems and Human Well-being: Policy Responses,* Volume 3. Chopra, K. R. et al. (eds). Washington DC and London, Island Press.

Miranda, M. and Sauer, A. 2010. *Mine the Gap: Connecting Water Risks and Disclosure in the Mining Sector.* World Resources Institute Working Paper (WRI). Washington DC, WRI. http://pdf.wri.org/working_papers/mine_the_gap.pdf

National Atlas of the United States. 2011. *Water Use in the United States.* http://www.nationalatlas.gov/articles/water/a_wateruse.html (Accessed 7 May 2011.)

NEPAD (New Partnership for Africa's Development). 2006. *Water in Africa: Management Options to Enhance Survival and Growth.* Addis Ababa, United Nations Economic Commission for Africa (UNECA). http://www.uneca.org/awich/nepadwater.pdf

NOAA (National Oceanic and Atmospheric Administration). n.d. El Niño Theme Page. http://www.pmel.noaa.gov/tao/elnino/impacts.html (Accessed 9 November 2010.)

Norman, E. and Bakker, K. 2005. *Drivers and Barriers of Cooperation in Transboundary Water Governance: A Case Study of Western Canada and the United States.* A report presented to the Walter and Duncan Gordon Foundation, November 8. http://www.watergovernance.ca/PDF/Gordon_Foundation_Transboundary_Report.pdf

Norman, E., Bakker, K., Cook, C., Dunn, G. and Allen, D. 2010. *Water Security: A Primer.* Program on Water Governance. Vancouver, BC, University of British Columbia. http://www.watergovernance.ca/wp-content/uploads/2010/04/WaterSecurityPrimer20101.pdf

OECD (Organisation for Economic Development and Co-operation). 2009. *Fact Book,* 2009. Paris, OECD.

Pereira, C. L. and Ortega, E. 2010. Sustainability assessment of large-scale ethanol production from sugarcane. *Journal of Cleaner Production,* Vol. 18, No. 1, pp. 78–82.

Postel, S. and Wolf, A. 2001. Dehydrating Conflict. *Foreign Policy,* 1 September.

PRB (Population Reference Bureau). 2011. *World Population Data Sheet: The World at 7 Billion.* Washington DC, PRB. http://www.prb.org/pdf11/2011population-data-sheet_eng.pdf

––––. 2008. *World Population Growth, 1950–2050.* http://www.prb.org/Educators/TeachersGuides/HumanPopulation/PopulationGrowth.aspx (Accessed 31 March 2011.)

Querol, M. 2003. *Estudio sobre los convenios y acuerdos de cooperación entre los países de América Latina y el Caribe, en relación con sistemas hídricos y cuerpos de agua transfronterizos.* LC/L.2002-P. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.eclac.cl/publicaciones/xml/2/13672/lcl2002e.pdf

Renault, D. 2002. *Value of Virtual Water in Food: Principles and Virtues.* Paper presented at the UNESCO–IHE Workshop on Virtual Water Trade, 12–13 December. Delft, The Netherlands. http://www.fao.org/nr/water/docs/VirtualWater.pdf

Roy, D., Barr, J. and Venema, D. H. 2010. *Ecosystem Approaches in Transboundary Integrated Water Resources Management (IWRM): A Review of Transboundary River Basins.* International Institute for Sustainable Development and United Nations Environment Programme.

SADC (Shared Watercourse Systems in the Southern African Development Community Region). 2008. SADC Revised Protocol on Shared Watercourses. http://www.sadc.int/index/browse/page/159

Shaban, A. 2009. *Monitoring Groundwater Discharge in the Coastal Zone of Lebanon Using Remotely Sensed Data.* Presented at Stockholm World Water Week, 16–22 August.

Shah, T, Makin, I. and Sakthiradivel, R. 2001. Limits to Leapfrogging: Issues in transposing successful river basin management institutions in the developing world. C. L. Abernathy (ed.) *Intersectoral Management of River Basins.* Colombo, IWMI–DSE.

SISS (Superintendencia de Servicios Sanitarios). 2011. *Informe de Gestión del Sector Sanitario 2010.* Santiago, SISS. http://www.siss.gob.cl/577/articles-8333_recurso_1.pdf

Smaller, C. and Mann, H. 2009. *A Thirst for Distant Lands. Foreign Investment in Agricultural Land and Water.* Winnipeg, Canada, International Institute for Sustainable Development (IISD).

Statistics Canada. 2010. *Human Activity and the Environment: Freshwater Supply and Demand in Canada 2010.* Ottawa, ON, Statistics Canada.

Stoltman, J., Lidstone, J. and Dechano, L. (eds). 2004. *International Perspectives on Natural Disasters: Occurrence, Mitigation and Consequences.* Dordrecht, The Netherlands, Kluwer Academic Publishers.

Stulina, G. 2009. *Climate Change and Adaptation to it in the Water and Land Management of Central Asia.* CACENA and Global Water Partnership.

Sydney Water. 2011. Hoxton Park Recycled Water Scheme. http://www.sydneywater.com.au/Majorprojects/SouthWest/HoxtonPark (Accessed 14 October 2011.)

The Economist online. 2011. Africa's impressive growth. *The Economist online,* 6 January. http://www.economist.com/blogs/dailychart/2011/01/daily_chart

United Nations (UN). 2009. *State of the World's Indigenous Peoples.* New York: United Nations, Department of Economic and Social Affairs. http://www.un.org/esa/socdev/unpfii/documents/SOWIP_web.pdf.

UNCTAD XII (United Nations Conference on Trade and Development). 2008. *Biofuels Development in Africa: Supporting Rural Development or Strengthening Corporate Control?* UNCTAD XII Workshop held in Accra, Ghana 12 May. https://files.pbworks.com/download/qbexQtTcy3/np-net/12638865/ACORD%20et%20al%20(2008)%20Biofuels%20in%20Africa%20Rural%20Development%20or%20Corporate%20control.pdf?ld=1

UNDESA (UN Department of Economic and Social Affairs). 2007. *World Population Prospects: The 2006 Revision, Highlights.* ESA/P/WP.202. New York: United Nations. http://www.un.org/esa/population/publications/wpp2006/WPP2006_Highlights_rev.pdf

––––. 2010. *State of the World's Indigenous Peoples.* New York, United Nations. http://www.un.org/esa/socdev/unpfii/documents/SOWIP_web.pdf

UNECA (United Nations Economic Commission for Africa). 2000. *Transboundary River/Lake Basin Water Development in Africa: Prospects, Problems, and Achievements.* Addis Ababa, UNECA. http://www.uneca.org/awich/Reports/Transboundary_v2.pdf

––––. 2001 *State of the Environment in Africa.* Addis Ababa, UNECA. http://www.uneca.org/water/State_Environ_Afri.pdf.

––––. 2006 *African Water Development Report.* Addis Ababa, UN Water/Africa and UNECA. http://www.uneca.org/awich/AWDR_2006.htm

UNECE (United Nations Economic Commission for Europe). 1998. *Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters.* Aarhus, Denmark, 25 June. http://www.unece.org/env/pp

––––. 2005. *Seminar on Environmental Services and Financing for the Protection and Sustainable Use of Ecosystems.* Geneva, 10–11 October. http://www.unece.org/env/water/meetings/payment_ecosystems/seminar.htm

––––. 2007*a*. *Our Waters: Joining Hands Across Borders – First Assessment of Transboundary Rivers, Lakes and Groundwaters.* New York and Geneva, UNECE.http://www.unece.org/env/water/publications/pub76.htm

––––. 2007*b*. *Recommendations on Payments for Ecosystem Services in Integrated Water Resources Management.* New York and Geneva, UNECE. http://www.unece.org/index.php?id=11663

––––. 2009*a*. *Guidance on Water and Adaptation to Climate Change.* New York and Geneva, UNECE. http://www.unece.org/env/water/publications/documents/Guidance_water_climate.pdf

––––. 2009*b*. *Transboundary Flood Risk Management: Experiences from the UNECE Region.* New York and Geneva, UNECE. http://www.unece.org/env/water/mop5/Transboundary_Flood_Risk_Managment.pdf

––––. 2009*c*. *Capacity for Water Cooperation in Eastern Europe, Caucasus and Central Asia. River Basin Commissions and Other Institutions for Transboundary Water Cooperation.* New York and Geneva, UNECE. http://unece.org/env/water/documents/CWC_publication_joint_bodies.pdf

––––. 2010. *The MDGs in Europe and Central Asia: Achievements, Challenges and the Way Forward.* Prepared by UNECE in collaboration with UNDP, ILO, FAO, WFP, UNESCO and other partners. New York and Geneva, UNECE. http://www.unece.org/commission/MDGs/2010_MDG.pdf

––––. 2011*a*. *Second Assessment of Transboundary Rivers, Lakes and Groundwaters.* New York and Geneva, UNECE. http://www.unece.org/?id=26343

––––. 2011*b*. *Setting Targets and Target Dates to Achieve Sustainable Water Management and Reduce Water-Related Diseases in the Republic of Moldova.* Report prepared in collaboration with the Swiss Agency for Development and Cooperation and the Government of the Republic of Moldova. http://www.unece.org/index.php?id=26819

UNEP (United Nations Environment Programme). 2006*a*. *Challenges to International Waters: Regional Assessments in a Global Perspective.* Global International Waters Assessment (GIWA) project. Nairobi, UNEP in collaboration with GEF, the University of Kalmar and the Municipality of Kalmar, Sweden, and the Governments of Sweden, Finland, and Norway.

––––. 2006*b*. *Environmental Indicators for North America.* Nairobi and Washington DC, UNEP. http://www.unep.org/pdf/NA_Indicators_FullVersion.pdf http://www.unep.org/dewa/giwa/publications/finalreport/giwa_final_report.pdf

––––. 2007. *Global Environment Outlook 4.* http://www.unep.org/geo/geo4.asp (Accessed 10 October 2011.)

––––. 2009. *Assessment of Transboundary Freshwater Vulnerability in Africa to Climate Change.* Nairobi, UNEP. http://www.unep.org/dewa/Portals/67/pdf/Assessment_of_Transbounday_Freshwater_Vulnerability_revised.pdf

––––. 2010*a*. *Global Envvironment Outlook: Latin America and the Caribbean (GEO LAC) 3.* Panama City, United Nations Environment Programme, Regional Office for Latin America and the Caribbean. http://www.unep.org/pdf/GEOLAC_3_ENGLISH.pdf

––––. 2010*b*. *Africa Water Atlas.* Nairobi: United Nations Environment Programme, Division of Early Warning and Assessment (DEWA), 2010. http://na.unep.net/atlas/africaWater/book.php.

––––. 2011. *GEO Data Portal.* 2011. http://geodata.grid.unep.ch/.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2010. *Aspectos Socioeconómicos, Ambientales y Climáticos de los Sistemas Acuíferos Transfronterizos de las Américas.* ISARM Americas Series No 3. Montevideo/Washington DC, UNESCO-IHP/OAS. http://www.oas.org/dsd/WaterResources/projects/ISARM/Publications/ISARMAmericasLibro3(spa).pdf

UNESCO-WWAP (World Water Assessment Programme). 2006. *La Plata Basin Case Study, Final Report. WWDR2.* Paris, UNESCO Publishing. http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/case-studies/

UN-Habitat. 2005. *Financing Urban Shelter: Global Report on Human Settlements 2005.* London and Nairobi, Earthscan and UN-Habitat. http://www.unhabitat.org/content.asp?typeid=19&catid=555&cid=5369

UN-Habitat. 2010. *The State of African Cities 2010: Governance, Inequality and Urban Land Markets.* Nairobi, UN-Habitat and UNEP.

UN Water/Africa and AMCOW (African Ministers' Council on Water). 2004. *Outcomes and Recommendations of the Pan-African Implementation and Partnership Conference on Water (PANAFCON).* Presented in Addis Ababa, 8–13 December, 2003. UN Water/Africa and AMCOW. http://www.uneca.org/eca_resources/publications/sdd/panafcon%20outcomes.pdf

––––. 2008. *Status Report on Integrated Water Resources Management and Water Efficiency Plans.* UN-Water. http://www.unwater.org/downloads/UNW_Status_Report_IWRM.pdf

US Census Bureau. n.d. *Population Profile of the United States.* http://www.census.gov/population/www/pop-profile/natproj.html (Accessed 31 March 2011).

United States Senate. 2011. *Avoiding Water Wars: Water Scarcity and Central Asia's Growing Importance for Stability in Afghanistan and Pakistan.* A report prepared for the use of the Committee on Foreign Relations, United States Senate. Washington DC, US Government Printing Office.

Valenzuela, S. and Jouravlev, A. 2007. *Servicios urbanos de agua potable y alcantarillado en Chile: factores determinantes del desempeño.* LC/L.2727-P. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.eclac.cl/publicaciones/xml/0/28650/lcl2727e.pdf

Waterwiki.net. 2009. *Facing Water Challenges in Istanbul.* http://waterwiki.net/index.php/Facing_Water_Challenges_in_Istanbul (accessed 7 May 2011).

WHO (World Health Organization)/UNICEF (United Nations Children's Fund). 2010. *Progress on Sanitation and Drinking-water: 2010 Update.* Joint Monitoring Programme for Water Supply and Sanitation. Geneva/New York, WHO/UNICEF. http://www.who.int/water_sanitation_health/publications/9789241563956/en/index.html

Woertz, E. 2009. Gulf food security needs delicate diplomacy. *Financial Times,* 4 March. http://www.ft.com/cms/s/0/d916f8e2-08d8-11de-b8b0-0000779fd2ac.html#axzz1BJ6wr0YH

World Bank. 2009. *Assessment of Restrictions on Palestinian Water Sector Development: West Bank and Gaza.* Report No. 47657-GZ, Washington DC, The World Bank. http://pwa.ps/Portals/_PWA/08da47ac-f807-466f-a480-073fb23b53b6.pdf

Wunder, Sven. 2005. *Payments for Environmental Services: Some Nuts and Bolts* . Center for International Forestry Research (CIFOR) Occasional Paper No. 42, Bogor Barat, Indonesia, CIFOR. http://www.cifor.cgiar.org/publications/pdf_files/OccPapers/OP-42.pdf

Yessekin, B. et al. 2006. *Implementing the UN Millennium Development Goals in Central Asia and the South Caucasus: Goal 7: Ensure Environmental Sustainability, Conserving Ecosystems of Inland Water Bodies in Central Asia and the South Caucasus.* Almaty, Kazakhstan and Tashkent, Uzbekistan, The Central Asian Regional Ecological Center and the Global Water Partnership for Central Asia and Caucasus. http://www.cawater-info.net/library/eng/gwp/ecosystem_e.pdf.

You, L. Z. 2008. *Irrigation Investment Needs in Sub-Saharan Africa.* Background Paper 9, Africa Infrastructure Country Diagnostic. Washington DC, The World Bank.

Young, C., Jacobi, S. and Andah, K. 2009. *Deriving Optimal Information from Inadequate Data Collection Networks for Water Allocation in Ghana. Proceedings of a Symposium* held on the island of Capri, Italy on 13–16 October, 2008, under the auspices of the International Association of Hydrological Sciences (IAHS) and UNESCO.

Zawya. 2011. MARAFIQ - Yanbu Power and Desalination Plant - Phase 2. *Projects Monitor*, 29 April.

Zimmer, D. and Renault, D. n.d *Virtual Water in Food Production and Global Trade: Review of Methodological Issues and Preliminary Results.* Rome, FAO Water.

PART 2

Managing Water under Uncertainty and Risk

INTRODUCTION

Author Daniel P. Loucks

Acting in an environment of uncertain change

The world is undergoing considerable change. Political and social systems are transforming in ways that are not always predictable, producing a variety of impacts. Technology is evolving and living standards, consumption patterns and life expectancies are all changing. Human populations are growing and increasingly moving to expanding urban areas while agriculture is expanding to feed them. Consequently, land use and cover is altering, as is the climate. The rates at which these changes occur are in many cases increasing, while their long-term impacts often remain uncertain. Discontinuities are possible and tipping points can exist beyond which change is irreversible. These changes can impact regional water cycles in ways that alter the quality, distribution and quantity of freshwater supply and demand.

Changes in daily lives, lifestyles, technology and environment will likely continue at an accelerated rate. Each day can bring new risks, uncertainties and opportunities. Humans experience more stress when expected to accomplish more of everything faster, more efficiently and with fewer resources. Change is a fact of life for everyone and everything that lives. Seasons change, people change, goals and emotions change, businesses change, and in part because of changing lifestyles and technology, so does the supply and quality of water available to meet the demands that result from these changes (see, for example, Jackson et al., 2001; Kates and Clark, 1996; Marien, 2002; Ostrom, 1990; Tansey and O'Riordan, 1999).

How can water managers plan for and adapt to increasingly uncertain future water resource conditions? How can water users plan for and adapt to the uncertainty of future water supply and quality? How can the people who create, regulate and adapt governance structures from local to global levels, within which we all operate and interact, meet the needs of all users living now and those who will live in the future? This includes the needs of our environment and the underprivileged and voiceless. How can society work together to increase levels of sustainability given uncertain future change (Vincent, 2007; Watkins and McKinney, 1997)?

Adapting to change presents an opportunity. What has happened in the past cannot be changed, but the future can be influenced by the decisions being made now. Water is a primary medium through which changes in human activity and the climate interact with the Earth's surface, its ecosystems and its people. It is through water and its quality that people will feel the impact of change most strongly. Without proper adaptation or planning for change, hundreds of millions of people will be at greater risk of hunger, poor health, energy shortage and poverty, water scarcity and pollution, and/or flooding (Anderies et al., 2004; Folke et al., 2002; Ganoulis, 2004; Holling et al., 2002; Lu, 2009; NRC, 1983; Pahl-Wostl et al., 2007).

Many people are concerned about the environment, but most tend not to take or advocate environmental action. Often the costs of possible remedial actions are deemed to be near term, whereas the benefits can be perceived to be further in the future. Another reason for inaction is uncertainty in determining the relative merits of different actions. Effective public policy-making requires that professionals work to clearly communicate the uncertainties surrounding alternative futures, how those uncertainties can be reduced, and which actions can provide the best assurance of desired outcomes in the face of those uncertainties (Cabinet Office Strategy Unit, 2002).

Uncertainty about the future is not an excuse for inaction. Decisions on water infrastructure investments, operation and management need to be made in the near term if benefits are to be obtained in the long term, that is, in the future. Waiting decades for more precise knowledge is not a feasible or acceptable excuse for inaction. Decisions regarding water infrastructure investments and operation are needed before the benefits of their services can be obtained, and hence such decisions will undoubtedly be based on uncertain data and assumptions. Exact knowledge about futures will never be available. All who impact water availability, how it is managed, and how it is used, even indirectly, need to make decisions based on non-precise information available at that time (Cosgrove and Rijsberman, 2000; Funtowicz and Ravetz, 1990; Morgan and Henrion, 1990).

Increased interaction among the interested public and scientists and policy-makers enables improvement in decision-making processes. This interaction needs to question and expand the range of policies that are proposed, debated and implemented. Participants need to help inform policy-makers and the public, and the public needs to make inaction unacceptable. Stakeholders can offer new ideas for political debate about how society and nature can be organized. They can test and explore all ideas to assess their relative merits. All stakeholders should visualize alternative futures, develop alternative policies for meeting the futures they like, and assess their likely impacts and uncertainties (NRC, 1996; Wildavsky and Dake, 1990).

What is known now or what can be assumed now? It is important to:

- Recognize that decision-makers in governments, the private sector and civil society, and all of us individually, deal with multiple issues involving risk and uncertainty. Particular decisions may or may not have been influenced by considerations of water, even though they may have an impact on water.
- Be aware of and understand the broader picture and what is happening in other sectors of the economy and society, so as to help inform the people making decisions in those sectors of their impacts on water, and of the impacts of water on them. Coordinated and synergistic management in related domains improves overall outcomes. After all, these sectors and domains are subject to the same or similar uncertainties that challenge water managers and users, and are continually engaging in risk management.
- Accept that change will continue into the future, and that much of it is largely beyond society's control. Consequently, approaches to water management should be adaptive, responsive and anticipatory.
- Approach sustainable water management as a journey along an adaptation pathway, rather than an arrival at a destination.
- Favour adaptation decisions that are robust to uncertainty in economic, social and ecosystem domains.
- Track emerging patterns and associated responses by strengthening monitoring networks and freshwater indicators.
- Shift from 'impacts thinking' to 'adaptation thinking', and adopt strategies that have a good chance of resulting in minimal, if any, regrets.
- Build change adaptation into all hierarchies of water resources management, from national to river basin and local actions.
- Secure environmental flows as one of the core objectives of water resources management to achieve balanced benefits for all.
- Manage existing and build and operate new water infrastructures in climate-smart ways.
- Include 'natural infrastructures' (e.g. wetlands, floodplains) in response options and employ them wherever feasible.
- Improve freshwater ecosystem connectivity and integrity.

'Impacts thinking' relies on the ability to predict the impacts of decisions. Current practice places great faith in the ability of analysts to predict the specific impacts of alternative decisions, which drive, or at least influence, change adaptation activities. This is reactive 'impacts thinking'; the problem is that the assumptions made and the impact topics selected by analysts can be too narrow, and are often uncertain. This is reflected in the estimated impacts or outcomes. 'Adaptation thinking' acknowledges the inherent uncertainty associated with model-based impact predictions and treats economic, social and ecosystems as dynamic entities that will likely differ from current and past states for multiple reasons. This approach promotes flexibility and continuous scenario development and analyses (Alcamo et al., 2000; van Notten, 2005).

Uncertainty constrains our ability to precisely qualify and quantify the risks associated with different management actions. The precautionary principle suggests that the greater the uncertainty (i.e. the less our capacity to precisely define or quantify risk) and the more catastrophic the possible outcome, the more cautious and 'reversible' the management actions should be (UNESCO, 2005). Although future research may help reduce some uncertainties, it may also uncover new uncertainties, which in fact increases our knowledge about what is uncertain and perhaps the range of that uncertainty. Uncertainty impairs future projections, and some of this uncertainty includes lack of confidence about what is uncertain. Surprises and unpredictable shifts in societal goals and needs are by their nature uncertain and as such cannot be accurately predicted.

Water planners, managers and users, and anyone who in any way impacts on the quantity, quality, distribution and use of water, can actively address uncertainty. Not all uncertainties can be reduced by further research, and even where reduction is possible it comes at a cost. Science can help articulate where and how to reduce uncertainty and under what conditions it cannot be reduced. There are limits to scientific knowledge and the role of scientists in decision-making.

The need to consider risk and uncertainty was acknowledged in the closing chapter of the third edition of the *World Water Development Report* (WWAP, 2009), with an emphasis on the consequences of inaction. Risk and uncertainty have long been a routine challenge for people managing and using water across all economic sectors and regions of the world. What is new is the recognition of the nonstationarity of hydrological processes, brought on by climate change, accelerated and unpredictable societal and economic development, and demographic dynamics (Koutsoyiannis, 2006; Milly et al., 2008). This has increased uncertainty and the associated risks, and made the task of risk management more complex and integral to decision-making.

Part 1 describes the national and global challenges of meeting planetary socio-economic objectives. What futures are possible? This second part of this report discusses the concepts and consequences of making decisions under risk and uncertainty, and how these can be factored into the decision-making process that impacts water resources. Water, being an input to all economic activities and life itself, is impacted by decisions made in a wide range of sectors or domains, themselves often having no direct involvement with water. Decision-makers also face multiple risks and uncertainties. Decisions are made and risk is managed in different ways in each sector or domain. Providing decision-makers with tools that show the broader water resource consequences of various decisions (actions, inaction) can substantially contribute to better overall resource management and reduced threats and adverse impacts (Bier et al., 1999).

Given uncertain future climates and land-use changes that alter water flows and storage, water managers are now asking: What level of protection is provided by the particular design of a levee or flood storage capacity in a reservoir? What protection against droughts is provided by specified active storage capacities in reservoirs together with particular operating policies? Exactly where is the 100-year floodplain boundary for the purposes of floodplain land-use zoning, and possibly insurance? Those responsible for making or influencing policy and investments are asking: Which among the various priorities are the most important if trade-offs become necessary? What measures can be taken to reduce risks? How much uncertainty can be incorporated into decisions, taking into account climate change and plausible social, economic, financial, cultural and environmental futures?

Part 2 discusses ways of analysing and responding to some of the challenges and risks. It concludes with examples of how both water management and socio-economic policy are already being used to address uncertainty and associated risks.

References

Alcamo, J., Henrichs, T. and Röschm, T. 2000. *World Water in 2025: Global modeling and scenario analysis for the World Commission on Water for the 21st Century.* University of Kassel, Germany, Center for Environmental Systems Research.

Anderies, J. M., Janssen, M. A. and Ostrom, E. 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and Society*, Vol. 9, No. 1, p. 18.

Bier, V. M., Haimes, Y. Y., Lambert, J. H., Matalas, N. C. and Zimmerman, R. 1999. A survey of approaches for assessing and managing the risk of extremes. *Risk Analysis*, Vol. 19, No. 1, pp. 83–94.

Cabinet Office Strategy Unit. 2002. *Risk: Improving Government's Capability to Handle Risk and Uncertainty.* London, HM Government Cabinet Office Strategy Unit. http://www.strategy.gov.uk/2002/risk/risk/home.html

Cosgrove, W. and Rijsberman, F. 2000. *World Water Vision: Making Water Everybody's Business.* London, Earthscan.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S. and Walker, B. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *AMBIO: A Journal of the Human Environment,* Vol. 31, No. 5, pp. 437–40.

Funtowicz, S. O. and Ravetz, J. R. 1990. Uncertainty and Quality in Science for Policy. Dordrecht, The Netherlands, Kluwer.

Ganoulis, J. 2004. Integrated risk analysis for sustainable water resources management. I. Linkov and A. B. Ramadan (eds) *Comparative Risk Assessment and Environmental Decision Making.* (NATO Science Series 38). Dordrecht, The Netherlands, Springer.

Holling, C. C., Gunderson, L. and Ludwig, D. 2002. In quest of a theory of adaptive change. L.H. Gunderson and C.S. Holling (eds) *Panarchy: Understanding Transformations in Human and Natural Systems.* Washington DC, Island Press, pp. 3–22. http://www.resilience.osu.edu/CFR-site/enterpriseresilience.htm

Jackson, R. B., Carpenter, S. R., Dahm, C. N., McKnight, D. M., Naiman, R. J., Postel, S. L. and Running, S. W. 2001. Water in a changing world. *Ecological Applications*, Vol. 11, No. 4, pp. 1027–45.

Kates, R. W. and Clark, W. C. 1996. Environmental surprise: expecting the unexpected. *Environment*, Vol. 38, No. 2, pp. 6–11, 28–34.

Koutsoyiannis, D. 2006. Nonstationarity versus scaling in hydrology. *Journal of Hydrology*, Vol. 324, pp. 239–54.

Lu, Z. 2009. *Applying Climate Information for Adaptation Decision-Making: A Guidance and Resource Document.* New York, National Communications Support Programme.

Marien, M. 2002. Futures studies in the 21st century: a reality-based view. *Futures*, Vol. 34, pp. 261–81.

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P. and Stouffer, R. J. 2008. Stationarity is dead: whither water management? *Science*, Vol. 319, No. 5863, pp. 573–74.

Morgan, M. G. and Henrion, M. 1990. *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis.* Cambridge, UK, Cambridge University Press.

NRC (National Research Council). 1983. *Risk Assessment in the Federal Government: Managing the Process.* Washington DC, National Academies Press.

––––. 1996. *Understanding Risk: Informing Decisions in a Democratic Society.* Washington DC, National Academies Press.

Ostrom, E. 1990. *Governing the Commons: the Evolution of Institutions for Collective Action.* New York, Cambridge University Press.

Pahl-Wostl, C., Sendzimir, J., Jeffrey, P., Aerts, J., Berkamp, G. and Cross. K. 2007. Managing change toward adaptive water management through social learning. *Ecology and Society*, Vol. 12, No. 2, pp. 30.

Tansey, J. and O'Riordan, T. 1999. Cultural theory and risk: a review. *Health, Risk and Society,* Vol. 1, No. 1, pp. 71–90.

UNESCO (United Nations Economic, Scientific and Cultural Organization). 2005. *The Precautionary Principle.* Paris, UNESCO World Commission on the Ethics of Scientific Knowledge (COMEST).

van Notten, P. W.F . 2005. *Writing on the Wall: Scenario Development in Times of Discontinuity.* Boca Raton, FL, Dissertation.com.

Vincent, K. 2007. Uncertainty in adaptive capacity and importance of scale. *Global Environmental Change*, Vol. 17, pp. 12–24.

Watkins, D. W. and McKinney, D. C. 1997. Finding robust solutions to water resources problems. *Journal of Water Resources Planning and Management,* Vol. 123, No. 1, pp. 49–58.

Wildavsky, A. and Dake, K. 1990. Theories of risk perception: who fears what and why? *Daedalus*, Vol. 119, No. 4, pp. 41–60.

WWAP (World Water Assessment Programme). 2009. *World Water Development Report 3: Water in a Changing World.* Paris/London, UNESCO/Earthscan.

CHAPTER 8

Working under uncertainty and managing risk

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Water managers and users are accustomed to working with – and making decisions under conditions of – risk and uncertainty. The predictability of water supplies derived from watersheds depends in part on nature, but precipitation, which typically becomes stream or river flow or infiltrates into a groundwater aquifer, is variable in character. The demands of water users can also vary and depend on uncertain population size and distribution, as well as on unpredictable weather and changing social and economic conditions. Costs and benefits of water treatment, distribution and use are always subject to uncertain market (and other) conditions. Technologies evolve and can offer new solutions, some as yet unknown or unimagined. Communities, corporations and irrigators, to mention a few users whose economic and social welfare depend on reliable supplies and qualities of water, have hedged their exposure to possible shortages and pollution, even prior to awareness that such uncertainties and risks are increasing due to changes in climate, population increases, lifestyle shifts and watershed conditions.

Water is vital for the production of almost everything. An average car tyre requires about 2 m^3 of water to manufacture; a ton of steel calls for 237 m^3; an egg requires about 0.5 m^3; and a single 200 mm semiconductor that powers a computer requires 28 m^3 of ultrapure water. As 'water footprints' grow, individuals, companies and entire cities will need to face the threat that there may soon not be sufficient water to meet all demands, both off and within watercourses (Hoekstra and Chapagain, 2008).

Some people may feel that water scarcity is not yet a cause for concern; after all, the world is covered with water. However, 97.5% of the planet's water is saltwater. The remaining 2.5%, of which only a fraction is accessible surface or groundwater, is used for essential functions, such as sustaining life, growing food, supporting various economic activities and ecological processes, producing energy, transporting cargo and assimilating wastes (Kumma et al., 2010; Palmer et al., 2008; UN-Water, 2006).

Uncertainties are exacerbated by the paucity or complete lack of reliable data on both supply and demand. In any region, no one can predict when and to what extent droughts or floods will occur. Both droughts and floods provide the potential for damage, in other words, risks; both create uncertainties regarding what action to take and when (Berstein, 1998; Brugnach et al., 2008; Giles, 2002; Hoffmann-Riem and Wynne, 2002; Kasperson et al., 2003; Rayner, 1992; Slovic et al., 2004; Tversky and Kahneman, 1974).

8.1 Concepts of uncertainty and risk

8.1.1 Some definitions

Risk commonly refers to an adverse event or the consequence of a decision. (see Section 8.1.2; see also Aven, 2003; Bedfore and Cooke, 2001; Cooke, 2009; Covello and Mumpower, 2001; Kaplan and Garrick, 1981; Kasperson et al., 1988; Mays, 1996; Slovic, 1992; Yoe, 1996).

Uncertainty is often used in connection with the term risk (sometimes even interchangeably). The most widely held meaning of uncertainty refers to a state of mind characterized by doubt, based on a lack of knowledge about what currently exists or what will or will not happen in the future. It is the opposite of certainty, which is a conviction about a particular situation (Bogardi and Kundzewicz, 2002; Morgan and Henrion, 1990; Pindyk, 2007).

Confidence level or interval applies to a population sampling, where variation or differences of opinion exist. Suppose a study needed to ascertain the percentage of homeowners on a floodplain who believe they will be safe from floods for the next 10 years, or the percentage of simulated floodplain development scenarios in which no flood occurred over a 10-year period. Depending in part on the sample size compared to the population size, that is, the number of people who could have been asked that question or the number of scenarios that could be simulated, a confidence level and interval can be determined. If the results in both cases were 85%, the results might be stated as 'We are 95% confident that 85% of those living on the floodplain think they will be able to avoid any flood damage in the next 10 years, with a margin of error of plus or minus 3%.' In other words one can be 95% sure that between 82 and 88% of the population believe they will stay dry over that ten-year period (Berger, 1985; Coles, 2001).

8.1.2 Risk and uncertainty in water

It is impossible to fully predict how well any water resource system will perform in the future. Such systems are subject to changing and uncertain inputs, and serve changing and uncertain demands. Risk and uncertainty characterize much of what water managers and socio-economic policy-makers must deal with. The more they understand these uncertainties and risks, the more effectively they can plan, design and manage water systems to reduce them.

Those who depend on water supplies or services provided by water cannot be certain that they will always have the water they need or want, or freedom from water hazards (i.e. floods or droughts or pollution). No one can fully depend on the recreational use of water in storage or in rivers or streams. No one dependent on hydropower can be assured of its reliable supply. In fact, nobody dependent on any energy type can be assured of its reliable supply, in part because of the uncertainty of needed water. This is the rationale behind the balanced development of water and energy options.

Knowledge in dealing with risks and uncertainties often comes from past experiences, observations and records. However, these are no longer adequate indicators of the risks and uncertainties faced by future water planners, managers, users and policy-makers, due to uncertainties generated by future changes in population growth and spatial distribution, water consumption patterns, socio-economic development, and climate variability and change. It is therefore crucial to understand the sources of uncertainty and learn how to analyse, internalize and cope with the risks that arise due to these uncertainties.

8.1.3 Understanding sources and types of uncertainty

Uncertainty can result from variability of an underlying process or incomplete knowledge of that process. Decision-makers are often required to make decisions, sometimes having considerable consequences and involving considerable expenditures of money, without knowing with adequate certainty the extent of those possible consequences and expenditures (Knight, 1921).

Sources of uncertainty related to water systems and their management include lack of data or random and systematic errors in data acquisition, recording and storage, inability to predict future processes that determine future supply and demand, and uncertainty about the various natural or physical processes of the water cycle.

Another source of uncertainty is social uncertainty. Human behaviour is unpredictable and, therefore, the behaviour of individuals, society and its institutions is also uncertain, as is, for example, market behaviour. Technical innovations, their perception and use, and their impact on our environment are also often unpredictable, and thus uncertain.

Uncertainty about the value of empirical quantities can also arise from imprecise use of language describing

"Risk perception and tolerance depend on a person's likelihood of harm, control over harm, extent of harm or hazard, voluntariness of exposure to possible harm, and trust in the sources of risk information."

information, and disagreement among different experts about how to interpret available evidence.

Finally, there is ignorance. Some aspects of hydrological systems are still not understood and some of these aspects are even unknown, so the question of what is not understood is itself not well understood. This makes it hard even to ask the right questions. These are the 'unknown unknowns'. Things we know we do not know may often be addressed and sometimes better understood through research. Things that we do not even recognize we do not know are only revealed by adopting an always-questioning attitude towards what we hear and see and measure and analyse (Walker et al., 2003).

8.1.4 Estimating the extent and duration of uncertainty

Changes in populations and their distribution on Earth, their lifestyles and their institutions, together with changes in the climate will undoubtedly change the water environment over the coming decades and centuries. The question is how. Uncertainties of supply and demand both in the short and long term will likely remain. While observations and analyses can reduce these uncertainties, in most cases, no single piece of evidence or experimental result can provide definitive answers to eliminate these uncertainties. In fact just the opposite is likely to happen over time. Decision-makers, planners responsible for making recommendations to decision-makers, and researchers predicting the likely future impacts of possible decisions are facing increasing uncertainties the further one looks into the future. Nevertheless, everyone making decisions that will impact future events needs informed judgments about plausible futures, even though they are uncertain. Probabilistic estimates of key quantities can all be useful to planning and assessment activities, such as the various extents to which it is drier or wetter or hotter or colder than usual due to the increase of atmospheric concentration of greenhouse gases; or estimates of the various heights of sea level rise as the average temperature of the Earth increases; or of various increases in demands for food in response to population and lifestyle changes, which in turn will impact demands for irrigation water and water use efficiency. Analysts seek to incorporate probabilistic descriptions into their models and analyses, usually by performing multiple simulations on fast computers, each simulation using a different input scenario or set of assumptions about the design and/or operation of the system being simulated. The results of these analyses can be presented along with their probabilities. Designs or policies that yield results acceptable to stakeholders across a wide range of model inputs are considered robust to changes in future conditions. Some of the tools used to identify such policies are described later in this chapter.

8.1.5 Understanding risk

Risk and its various descriptions are highly influenced by individual and social perceptions. Risk perception and tolerance depend on a person's likelihood of harm, control over harm, extent of harm or hazard, voluntariness of exposure to possible harm, and trust in the sources of risk information. As risk perceptions can affect collective and individual choices, decisions may benefit from making risk more explicit. Examples of current water-related risks are water scarcity, quality degradation, loss of ecosystem services and extreme hazardous events, which in turn may be influenced by socio-economic developments and decisions (Ganoulis, 1994).

Awareness of risks and the importance placed on them depends in part on time horizons. This is an issue for climate change, because changes are expected to occur over decades rather than years. Society has a problem with deciding what to do about events whose probabilities of occurring are very low but will provoke severe consequences if they do happen, such as the collapse of a dam or the occurrence of a one-in-a-thousand-year flood or a catastrophic water-related epidemic. These problems have given rise to criteria like the precautionary principle and the concept of safe minimum standards, which will be discussed later. However, concern for the extreme consequences of low probability events to the exclusion of dealing with much more common variations with much higher probabilities is not desirable.

8.1.6 Model uncertainty

Any model of a social or natural system is a simplified approximation of that system. Models are used to better understand such systems and estimate the possible impacts of various decisions affecting those systems.

In general, the most preferred and useful model is the most simple and understandable one that provides the needed or desired information with the needed or desired accuracy. The choice of model used for any analysis will depend in part on the available scientific knowledge and data, and the intended use of the model output. In this sense, the choice of a model is subjective and pragmatic.

Uncertainty about the functional form of (the assumptions built into) a model can arise just as can uncertainty about the quality of its input data. Both can lead to disagreements among different experts about how to interpret the model output. A fundamental problem and potential source of uncertainty is that the people who perform analyses are often not clear about the objectives and decision rules that they should assume and incorporate within their models. In such cases it makes sense for model operators to provide a range of options to the stakeholders and decision-makers, each representing a different mix of various objectives.

8.1.7 Thresholds and tipping points

The term 'tipping point' commonly refers to a critical threshold at which a relatively small perturbation can qualitatively alter, perhaps irreversibly, the state or development of a system (Brugnach et al., 2003; Gladwell, 2000; Lenton et al., 2008; Keller et al., 2008; Walker and Meyers, 2004). Tipping points related to changes in Atlantic thermohaline circulations, the die-back and loss of Amazon rainforest, and the melting of the Greenland ice sheet have received recent attention in the press. In each case, scientists believe that there is a chance that the gradual changes that take place in the state of these systems over time will at some point in the processes become irreversible. This can have long-term consequences for those systems.

The definition of tipping point could in principle be applied in other situations at any time, for example, decisions made with respect to governance of countries, or with respect to military actions. More common examples of tipping points apply to structures made by engineers. Metal fatigue is a well-known phenomenon, associated with aircraft. With increased use aircraft begin to exhibit cracks in the wing and tail structures. Periodic inspections provide a way to monitor these cracks and prevent them from reaching a tipping point, which can result in entire wing failure or control failure due to loss of tail components.

BOX 8.1

Dutch Delta Approach

In 2007, the government of the Netherlands implemented a study of the impacts of sea level rise as a result of expected climate change in combination with land subsidence, urbanization and increasing peak discharges of major rivers. Their goal was to determine how best to make the country resilient to worst-case climate change conditions. Problems surrounding the upkeep of long-term livelihoods in fragile deltas under climate change, urbanization and land subsidence are universal, but strategies to cope with them require tailoring to local circumstances. The national Delta Commission oversaw the study, members of which included renowned scientists (not only in the field of water, but also food, spatial planning and climate), as well as representatives from the finance sector and private contractors. All interests were represented. Their tasks included exploring where present policies are inadequate to cope with worst case (climate) change, identifying what and when 'tipping points' may apply, that is, the point at which certain policies or measures become technically impossible, financially unaffordable or socially unacceptable; developing a future vision about where Delta people would wish to live in 2100; deriving strategies starting from the tipping points for how to realize the desired vision or move towards it; ensuring flexibility to be able to adjust to slower or faster changes or changed values of future generations, starting with no-regret measures; and ensuring long-term implementation through a Delta Fund, a Delta Commissioner and a Delta Law. Within three years the Dutch Government had a vision to make the country climate resilient, passed a Delta Law in Parliament, created a Delta Fund, appointed a Delta Commissioner and agreed on a Delta Implementation Plan.

Source: Policy Research Corporation (2009).

Box 8.1 refers to tipping points that some may consider as 'branching points' in scenarios. They would argue these branching points or decision points are not tipping points in a strict scientific sense.

8.1.8 Nonstationarity

Water resources management, water infrastructure planning and design rely on an understanding of the water cycle and hydraulics as they apply to particular sites. For the purposes of planning and design, engineers have typically assumed that the hydrological processes in a particular watershed or basin could be described by probability distributions that were not changing over time; that is, the historical statistical characteristics of those processes were assumed essentially constant over time, or stationary. The more these extreme events happen due to changes in the Earth's climate or from unpredictable human behaviour, the more challenging it is to plan and manage water. The question is how best to include these nonstationarity considerations of both water supply and demand in water planning and management. Because of this, water resources planners and managers must apply a significant amount of judgment in their analyses, due to changes in land use, urbanization, and the impacts of a changing climate that influence future precipitation, evaporation, groundwater infiltration, surface runoff and channel flow (Aerts et al., 2011; Block and Brown, 2009; Folke et al., 2004; Hamilton and Keim, 2009; Holling, 1986).

The more these extreme events happen due to changes in the Earth's climate or from unpredictable human behaviour, the more challenging it is to plan and manage water. Understanding the changes taking place in river and aquifer systems constitutes an important challenge for water managers. The question is how best to include these nonstationarity considerations of both water supply and demand in water planning and management.

8.1.9 Other key concepts

Lack of knowing what is unknown is an extreme state of uncertainty. Many of the defining events, technological developments and scientific discoveries of recent times were unknowable and even unimaginable a few decades ago.

Indeterminacy is the uncertainty that comes from not fully understanding the performance characteristics of complex systems. It arises because complete or perfect knowledge of complex systems, which would permit the credible calculation of probabilities of various outcomes, rarely exists. Likewise, the full range of potential outcomes is usually not known.

Reliability indicates the probability of one or more performance indicator values being considered satisfactory. The concept depends on a threshold value that separates satisfactory and unsatisfactory values of each indicator or measure of performance. There can be various levels of reliability associated with multiple threshold levels (Duckstein and Parent, 1994; Hashimoto et al., 1982; Plate and Duckstein, 1988).

Robustness indicates how well a system performs over a range of possible input scenarios pertaining to what is uncertain (Hashimoto et al., 1982).

Resilience is a measure of the ability to adapt to changes and recover from disturbances, while providing options for future developments (Fiering, 1982, Hashimoto et al., 1982; Holling, 1973; Walker et al., 2004).

Regret is a measure of an unsatisfactory state resulting from a decision. Systems can be designed and operated to minimize the maximum (worst) regret that could occur or maximize the minimum (worst) level of performance. Both minimax and maximin objectives attempt to reduce the most extreme risks or consequences of failure.

Surprise occurs when there is an abrupt or discontinuous change in a physical or socio-economic system that is unexpected.

Vulnerability is an important measure, along with reliability, associated with any performance indicator. Its various forms (expected, maximum, confidence level) indicate the consequences of a failure, should a failure occur (Hashimoto et al., 1982; Heltberg et al., 2009).

8.2 How uncertainty and risk affect decision-making

It is common for decision-makers dealing with water to have to make choices without knowing with certainty the outcome of their decisions. This uncertainty of outcome and the decision-makers' attitudes towards risk invariably impact their decisions (Walker et al., 2003).

For example, a farmer must make planting decisions without knowing how much rain will be available, and its distribution over the growing season. The outcome of his planting decisions will be unknown until the time of harvest. Alternatively, an expanding firm wants to construct a new building and must choose a location. New Orleans is a location which poses significant rewards, but the company is uncertain if weather (e.g. hurricanes) will strike and result in a large loss. In another example, the price a potential homeowner is willing to pay for a house may depend on the risk of it being flooded. Whether the house is going to be flooded is uncertain, but if it is built on a floodplain the risk exists. That risk may be mitigated in part by flood-proofing or by purchasing flood insurance to recover the economic loss.

The decisions people make under uncertainty also depend on their attitude towards risk. For example, if a mayor of a town is face with the choice of increasing the level of protection of a levee, which could reduce flood damage considerably, or spending that money on road maintenance, that mayor must consider the likelihood of a flood occurrence as opposed to generating, perhaps, more immediate and continuing public appreciation and support by improving the condition of the town's roads. If the mayor opts for road maintenance and a flood does occur, resulting in damage, public appreciation and support will disappear. If the mayor is risk averse, even though the probability of a flood may be low, he or she may not wish to take the risk of incurring a large loss and lose public support, as a result of lack of adequate flood protection (see Box 8.2).

Different people perceive risk differently, depending on the context or environment in which the decisions are made. Managers do not always consider the risks as inherent to the situation, and avoid accepting risk by considering it as subject to control. Many believe that by using their skills they can reduce risk. Others rely more on their subjective judgments than on mathematically based analyses. The more catastrophic the consequences of making the wrong decision, the less likely managers will make decisions that accept risks explicitly.

When faced with a problem or decision that involves risk, managers can either accept the risk or attempt to reduce it before making the decision. Ways of reducing risk include conducting further analyses and collecting more information. In some cases, such as for hedging against incurring flood damage, it might be possible to buy insurance. This transfers some of the risk to a third party, reducing the consequences of a risk. It might also be possible to carry out pilot studies before making major infrastructure decisions, for example, advanced desalination or wastewater treatment technology, or letting the supplier take part of the risk and making this clear in the purchase contract. Finally, the decision once made can include provisions for future modifications, if possible, or if not it should be sufficiently robust for a range of future conditions (Alerts et al., 2008; Burton, 1996; Callaway et al., 2008; Dessai and van der Sluijs, 2007; DETR, 2000; Elshayeb, 2005; Liu et al., 2000; Lofstedt, 2003; Miller and Yates, 2006; NRC, 2000; UNDP, 2004; van Aalst et al., 2007; UNDRO, 1991).

8.2.1 Approaches to inform decision-making under risk and uncertainty

When sufficient information is available to determine probabilities of decision outcomes and evaluate the consequences, decision-making can be based on risk analysis. Decision-making may be assisted by the use of a wide variety of analytical tools and techniques, varying from the simple to the sophisticated (Downing et al., 1999; Frederick et al., 1997; Green et al., 2000; Hobbs, 1997; Karamouz et al., 2003; Li et al., 2009; Loucks and van Beek, 2005; NOAA, 2009; Simonovic, 2008; Willows and Connell, 2003). The result is either

BOX 8.2

Queensland, Australia, warned of floodplain risks

The interim flood inquiry report into the January 2011 statewide flooding disasters, entitled *Understanding Floods: Questions and Answers*, by the Queensland Floods Science, Engineering and Technical Panel, calls for a new test of what constitutes appropriate development. The report says that flood-risk planning should consider 'a combination of the chance of a flood occurring and the consequences of the flood for people, property and infrastructure'.

'It is estimated that flooding so far this year (August, 2011) has caused AUS$2 billion damage to local government infrastructure in Queensland, with total damage to public infrastructure likely to reach AUS$6 billion. Damage to the Australian economy from flooding, in New South Wales and Victoria will top AUS$30 billion. ... There were 37 deaths, 35 in this state.' This shows that flooding of some locations may have significant economic and social consequences for a much wider region.

Source: Hoffman (2011).

BOX 8.3

US Corps of Engineering risk analysis

Risk analysis has been used and is applicable to a wide range of decision problems within the US Army Corps of Engineers. Risk analysis is not only for extreme or low-probability events, but also for any situation in which there is a range of possibilities. Ongoing examples of the use of risk analysis include:

- Examination of economic benefits of rehabilitation of the levees along various rivers and lakes, taking into account uncertainties of storms, river or lake stages and levee performances.
- Comparison of alternative rehabilitation plans for hydropower generators/turbines, making use of probabilities of failure of generators and turbines and maintenance and rehabilitation costs.
- Examination of navigation improvement plans for portions of the Gulf Intracoastal Waterway based on minimizing delays to barge traffic and incorporating uncertainty in tow trips and travel time.
- Flood Damage Assessments using a software system for performing an integrated hydrological and economic analysis during the formulation and evaluation of flood damage reduction plans. This embodies risk-based analysis procedures to quantify uncertainty in discharge-exceedance probability, stage-discharge and stage-damage functions. These approaches have been used in the Louisville, New Orleans, Mobile, Fort Worth, Galveston, Honolulu, Kansas City, Los Angeles, Omaha, Portland, San Francisco, Savannah, St. Louis and St. Paul districts among others.

Source: Males (2002, pp. 3–4).

a benefit–cost–risk analysis (or simply a cost–risk analysis), or a reliability analysis, depending on the purpose of the modelling exercise. Any risk analysis should provide estimates of the level of confidence that a particular performance measure or criterion will be met (Box 8.3).

Informed decision-making is increasingly becoming a bottom-up process. Where risks and uncertainties prevail the experts have no monopoly on what might happen in the future or what might be sustainable. Everyone's opinion is needed, especially the impacted stakeholders, who can determine the success or failure of any decision. Integrated water resources planning and management (IWRM), by definition, involves the participation of all interested stakeholders. Interactive decision-support models have been developed and successfully used to facilitate stakeholder participation. The purpose of such modelling tools is to help achieve, if possible, a shared vision of how a particular water resource system functions, and the likely impact of any decisions on system performance.

8.2.2 Strategies for dealing with uncertainty

The importance of reducing the structural vulnerability of (water) systems has gained increasing attention during the last few years. The development of water management strategies and infrastructure with high levels of flexibility – or robustness – will almost certainly contribute to system resilience, including recoveries from the unexpected. However, the question remains of how to evaluate the appropriateness of such strategies. Traditionally, this has been done through risk management on the basis of historical data and statistical analysis, with strategies selected using, for example, a cost–benefit–risk analysis. Other decision-support tools are required when risks cannot be quantified or isolated, as in cases where the many factors described in Chapter 1 interact.

In complex water management problems where climate is a factor, many years or decades may pass during which understanding of the problem may increase, but so might the uncertainty. This applies even more to socio-economic and behavioural uncertainties. There are two decision-making/management strategies that may help inform decision-makers:

1. *Adaptive strategies:* Choose strategies that can be modified to achieve better performance as one learns more about the issues at hand, and how the future is unfolding. These adaptive strategies can be responsive to new goals or objectives of system performance as well as changing inputs over time.
2. *Robust strategies:* Identify the range of future circumstances, and then seek to identify approaches that will work reasonably well across that range. This strategy applies especially to decisions that cannot easily or cost-effectively be modified in the future.

Adaptive strategies are based on the assumption that the future impacts of any decision taken now are unknown. In such cases, one could engage in further research to better understand the potential results of any decision, and make a decision following successfully completion of the research. However, in the intervening time, opportunities for increased economic and environmental benefits or reduced costs or damages may have been missed. Alternatively, a decision can be made now, based on the best judgment and knowledge at hand, followed by monitoring of the results to see if the decision was correct, or requires further adjustments in the future. The latter is termed 'adaptive decision-making'. Monitoring is critical to the success of adaptive strategies. They work best when the decision timescales are well matched to the changes being observed (Box 8.4).

Alternatively, a robust strategy performs well over a wide range of future scenarios. It is especially appropriate when adaptive strategies cannot be easily

> "Adaptive strategies are based on the assumption that the future impacts of any decision taken now are unknown."

implemented, such as for establishing the capacity of a reservoir or flood control structure intended to last a long time. A robust strategy contrasts with an optimum design strategy, whose performance may degrade rapidly under different assumptions regarding inputs and parameter values. Such a strategy may result in slightly less than optimal performance so as to improve performance if unlikely events actually happen.

In contrast to a robust design, whose performance will be satisfactory under a range of future possible scenarios, a *resilient system* is one in which failure or an unsatisfactory state are quickly remedied (i.e. the system can recover or enter a satisfactory state relatively quickly). One definition of resiliency is the probability of becoming satisfactory over a set period of time, given an unsatisfactory state. A resilient system can recover speedily from a failure state. Often design and operation options are available to make a system more robust and resilient, and hence less vulnerable.

Risk-adverse decisions may often reflect a minimax regret criterion for determining which of many possible alternative decisions is 'best.' Deciding on the alternative that minimizes the maximum regret, or 'risk' that could result from the decision, satisfies this criterion. Consequences of decisions depend on unknown outcomes. For example, deciding to drill a water supply well entails a cost that will be wasted if water is not present, but will bring major benefits if it is.

Additional information related to adaptive and robust policies applied to the management of water and aquatic ecosystems can be found in Blumenfeld et al. (2009); Carpenter, Brock and Hanson (1999); Chen et al. (2009); Folkes et al (2002), MA (2005); Sanders

BOX 8.4

Adaptive strategies for responding to drought and flood in South Asia

'Floods and drought are fundamental challenges throughout South Asia, and their impact is heavily influenced by larger water management issues. Current responses to both floods and drought are dominated by humanitarian relief, without concurrent development of long-term adaptive mechanisms with functioning institutional support. In the current era of globalization and … of global climate change, global and regional searches for effective climate change response strategies are taking place.

'Effective small-scale, innovative local coping strategies that are influenced by a range of economic, demographic and social factors do exist, and these need to be given attention, but up-scaling these to a higher level is difficult. The lack of information flow in both directions is a key problem. Despite an expanding network in this field, few have solid field level strategies and few local groups have links to regional and global debates.

'[An Adaptive Strategies project was initiated in India in an] attempt to reconcile differences in perceptions of and responses to extreme weather events in the context of climatic and social change. The project was designed to document and flesh out concepts and opportunities for more effective approaches to water management and flood and drought mitigation through an integrated set of studies in four field locations: two drought affected areas in the arid regions of Rajasthan and Gujarat (India) and two flood affected areas along the Rohini and Bagmati River basins across the India-Nepal border.'

The studies identified existing coping strategies of communities in drought and flood affected areas and suggested patterns of social and economic change that influence the vulnerability of livelihoods to drought and flood conditions and the opportunities for reducing the risks of damage and hardship during such events in those areas.

Source: Reproduced from ISET (2010).

and Lewis (2003); Stuip et al. (2002); Tallis et al. (2008); and Le Quesne and Matthews (2009, 2010).

8.2.3 Scenario analysis

Scenarios are an appropriate and tested approach for dealing with uncertainty for many reasons:

Need for a long-term view. To analyse water issues in the context of sustainable development requires a long-term view that takes into account the slow unfolding of some of the hydrological and social processes involved, and allows for the necessary time for waterworks investments to yield their benefits.

High uncertainty about the system. In situations where it is difficult to assign probabilities to possible events or future outcomes, for whatever reason, one can still generate possible scenarios of what could plausibly happen in the future that would have an impact on the performance of the system being planned, designed, or operated. Even though the probability of any created scenario actually happening will likely be 0, such a set of possible scenarios helps planners, designers and operators to learn how their system will likely perform under a range of possible futures. These future scenarios will typically include both uncontrolled natural events, as well as human decisions. The future behaviour of people and institutions is as much a part of a scenario as is, for example, the climate.

Need to include non-quantifiable factors. To understand system impacts associated with any of the generated scenarios, each scenario is usually simulated over time, and various indicator values are computed for each time period simulated. These indicators will inevitably include qualitative as well as quantitative values. Both qualitative and quantitative simulations may be appropriate to capture and evaluate as best as possible the cultural and political impacts that one might expect from the particular system being considered.

Need scenarios that provide integration, breadth and perspective. Water systems serve numerous agricultural, domestic and industrial demands, as well as demands for in-stream recreational as well as environmental flows. They are impacted by changes in land use, human lifestyles, economic and social conditions, political decisions and the need for energy. Scenario development must capture all of this interdependency and complexity among system components, as appropriate. It must also provide a perspective that covers the interests and concerns of stakeholders at the local, regional and national levels, again as appropriate.

Need to organize understanding for decision-making. The use of scenarios and associated simulation models addresses the need to simulate decision-making and stakeholder participation. Ideally, such simulations will be interactive involving potential planners and decision-makers, as well as stakeholders, making decisions in response to events taking place in the simulations. Alternatively, decision rules can be defined that will serve to make the decisions in a simulation run, but it is preferable if there is interaction between the simulation models and participants during the simulation. This allows more attention to be focused on cause and effect, on when decisions need to be made, and on what constitutes a branching point, where human actions can significantly affect the future. Such simulations should aim for a shared vision of how a system may perform, among stakeholders who may hold different points of view as to how they wish it to perform.

Change, discontinuities, ‘wild cards’, potential surprise and other altered conditions, whose probability may be assumed to be very low, are often ignored and omitted even though their impact could be great (see, e.g., Marien, 2002; Rahmstorf and Ganopolski, 1999; van Notten, 2005, 2006).

One way to make this class of uncertainties operational is through surprise scenarios. Different methods have been proposed, such as ‘historical analogy’ or ‘surprise theory’, in which underlying principles of surprise are studied systematically by ‘thinking the unthinkable’ – imagining unlikely future events followed by the construction of plausible scenarios that could be associated with them.

8.2.4 Backcasting

Backcasting is an alternative scenario approach for the exploration of alternative futures. It aims to circumvent the tendency of treating the future as an incremental continuation of the past, and to provide as much information as possible on future uncertainties. Instead of taking the present as the starting point, backcasting starts with the articulation of one or more desired (or even undesired) futures and then tries to identify possible actions that lead to them and bottlenecks that would hinder or prevent reaching them. Backcasting is an iterative process in which future visions and policy interventions are (re)adjusted (see also Figure 8.1). Iteration is usually required to resolve internal inconsistencies and mitigate adverse economic, social and environmental impacts that are revealed in the course of the analysis. The main results of backcasting studies are generally alternative images of the future, thoroughly analysed in terms of their feasibility and consequences.

A backcasting exercise generally follows four different steps. The first step is a creative process of defining a desired (or undesired) future (or futures). The next step works backwards from that defined future to identify strategies, measures, policies and programmes that will connect the future to the present. This creative phase is then followed by an evaluation of assumptions underlying these futures in terms of feasibility, and the consequences of alternative images of the future, reflecting on the implications of the long-term perspective for short-term policy-making. After identifying policy interventions, actions and events needed to realize (or avoid the realization of) the (un) desired future, the original future vision is generally adjusted.

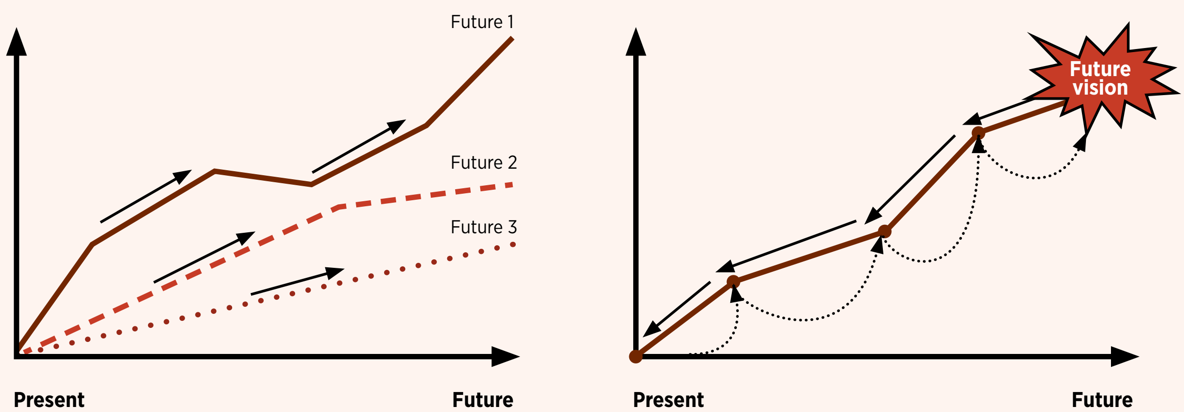
Over the years, backcasting has been applied regularly in the development of climate-mitigation strategies (for the reduction of greenhouse gas emissions). For water management discussions, backcasting is a relatively new approach. The World Water Vision of the World Water Council (Cosgrove and Rijsberman, 2000) was a qualitative backcast scenario using elements of three other scenarios. Backcasting was recently used to develop adaptation strategies to 'climate proof' the Netherlands.

8.2.5 Institutional decision-making principles and paradigms

Today decisions are being made under conditions of risk and uncertainty where the probabilities are nonstationary. Their values are unknown and incapable of being estimated based on the current state of modelling. This makes the estimation of risks of adverse impacts virtually a meaningless exercise for the purposes of water management and water use. Hence when dealing with nonstationarities, a substantially different water management approach seems appropriate, yet one based on a foundation of existing principles and evaluation techniques. This approach, essentially an adaptation of existing proven principles and techniques, has been termed 'robust decision-making': a

FIGURE 8.1

Backcasting versus forecasting scenarios



The forecasting scenario process:
- Identification of drivers
- Formulation of narrative storylines
- Fleshing out of storylines
- Identification of robust solutions

The backcasting scenario process:
- Formulation of (un)desirable future(s)
- Identification of policy interventions, actions and events
- Evaluation in terms of feasibility
- Adjusting original future(s)

Source: van 't Klooster et al. (2011).

process designed to accommodate uncertain scenarios with evaluation and project justification principles that focus less on optimal outcomes and more on producing robust solutions.

Planning the design and operation of water resources infrastructure, whose life extends decades into the future, is a challenge for several reasons, especially if the design cannot easily or inexpensively be changed once built, such as a reservoir. One reason is the change nature of hydrology, and the uncertain nature of those changes. What will constitute hydrology in the next 50 to 100 years is simply unknown. Again, we can guess using hydrological scenarios. It is likely that the changes over the next decade or two will not be significant, which will enable historical records to be of assistance in predicting future scenarios. Another reason is that the future benefits and costs derived from the infrastructure project or system being considered are negligible when discounted to the present, but not so for those living some 50 or 100 years from now. Clearly, there is a need for evaluation criteria that consider the value of sustainable systems now and on into the future. This needs to be responsive to the interest rates used in any benefit/cost analysis, performed at any time by future users of the system, as well as to the level of risk and uncertainty, even if the latter cannot be quantified. (Bardhan, 1993; Hall, 2003; Keeny and Raiffa, 1993)

8.2.6 Acknowledging the need to adapt design procedures

There is no doubt that recent years have witnessed changes in land use, water consumption and global climate, while uncertain future changes and rates of change give real cause for concern. Water management agencies should be as troubled by this as scientists, and need to work towards improved methods of assessment, so as to better incorporate the uncertainty introduced by lack of stationarity in future conditions.

A major question for planners and engineers should be: Is there a better way to plan and design and operate sustainable, reliable, resilient and non-vulnerable water resources systems in the face of this nonstationarity?

If the assumption of stationarity is no longer justified, a replacement strategy is needed to meet planning and design requirements. If a consensus is then reached among scientists and engineers on the best replacement, it must be accepted and implemented in government water management agencies.

Water management agencies with issues and policy matters need to participate in the development of alternate methodologies that incorporate nonstationarity, so as to make water resource projects more adaptable, sustainable and robust. Participation in any improved planning and design methodology that takes into account the nonstationarity of hydrological, as well as social processes, will help in its implementation within the agency bureaucracy. This may entail new legislation and authorization.

It may be easier to implement new methodologies into the planning and design of new projects than into the operating rules of existing projects, as these are often specified by law and may be harder to change. To enable operating rules to take into account nonstationarity, it may be necessary to determine whether or not to develop and adopt new operation plans. Model studies of potential changes resulting from nonstationary might suggest the need for increased flexibility, so as to adaptively manage operations to increase system performance with respect to various criteria.
Institutions involved in implementing any planning model are obligated to achieve some level of consensus on exactly what parameters will be impacted by nonstationarity, and what range of variation can be expected on a regional basis. The method of

> "The results from quantitative and qualitative analyses, based on science and economic principles, are often considered less relevant than political factors, emotion, religious beliefs and just gut feelings based on intuition."

implementation must be consistent and reproducible. Changes in established procedures are never easy in large governmental institutions. Considerable study and collaboration and communication among all interested stakeholders should be expected before a change can be implemented.

Until consensus on a new methodology is reached, agencies will continue to use existing procedures, even though the uncertainty associated with these procedures is increased due to potential impacts of changes in climate variability and land use. In addition, there is always less risk of being criticized if established procedures are used, even if they may be inferior to others.

It is unlikely that water management agencies will want to modify existing water management operations without a convincing argument that there is a better way that leads to better results, however measured. Considerable study of alternative methods is needed. The ultimate solution will surely involve a multidisciplinary approach to understanding the science and the development of guidelines and regulations that integrates the relevant science into water resources planning approaches and activities (Baggett et al., 2006; Frederick and Major, 1997; Palmer et al., 2008; Wardekker et al, 2008).

8.2.7 Behavioural decision theory

Most important real-world decision problems are determined by more than one decision-maker. Decisions are worked out and implemented through government, private sector and civil society organizations. The results from quantitative and qualitative analyses, based on science and economic principles, are often considered less relevant than political factors, emotion, religious beliefs and just gut feelings based on intuition. One of the more important aspects of decision-making under uncertainty concerns the processes by which organizational structure influences the success of an organization in coping with uncertainty, and the strategies they adopt to make themselves less susceptible to failure.

These factors are discussed extensively within the 'behavioural decision theory' or risk-related decision-making literature. In contrast to decision analysis, which outlines how decisions should be made in the face of uncertainty, behavioural decision theory describes how people actually make decisions when not influenced or supported by analytical procedures such as decision or benefit-cost-risk analyses. It describes how rational and emotional parts of the human psyche interact in decision-making (Camerer and Weber, 1992; Loewenstein and Cohen, 2008; Marris et al., 1997; Wolt and Peterson, 2000).

8.2.8 Precautionary principle

In the presence of uncertainty, many actions and decisions taken to achieve increased economic, environmental and social benefits will have impacts that one cannot now predict. Actions may be needed to reduce these risks if there is a chance that any of these impacts will be harmful to people or the environment in the future, the precautionary principle places on those proposing such actions the burden of proving that the proposed decisions, including those needed to protect people and the environment from future harm, will not be harmful to anyone or anything in the future. This introduces a condition to be met before such decisions can be made and places the responsibility for meeting this condition on decision-makers. This principle comes from the belief that there is a social obligation to protect people and their environment from damages that could result from any decision being considered. Following this principle, decisions to proceed with a project or programme can only be taken once evidence is available that no harm, especially irreversible harm, will result (UNESCO, 2005).

8.2.9 Diversification

Other strategies for enhancing robust decision-making under uncertainty accept that the future is unpredictable and aim at developing methods and measures that build on existing knowledge. The more diverse the current water system is, the more resilient it should be to unexpected events.

There are several steps required to diversify water management decisions and investments. The first step is to assess possible interventions and their related costs. Consider, for example, a semi-arid area that is largely dependent on water for its main economic activity: rainfed agriculture. As the economy depends on the success of rainfed crops, the challenge for a water manager is to develop new drought mitigation measures, such as increasing storage capacity of surface water, increasing groundwater capacity, and devising irrigation schemes for local farming communities. Water managers inform decision-makers, who can also play an active role by introducing water pricing policies, subsidies or other financial mechanisms, or by deciding on a different development strategy, among others. The choice of which measures to invest in depends on available budget, acceptance by the public (voters and tax payers) and major user groups, and geographical conditions. The cost-effectiveness of each measure will depend on how trends such as climate change or future economic conditions determine the effectiveness of each measure, and hence the success of combinations of measures.

Investment diversification – in analogy with portfolios in the stock market – can reduce the risk of the total portfolio of water measures if a country can afford it. Uncorrelated (or partly-uncorrelated) investments in water management measures that aim to achieve similar returns can result in different effects under the same future trends. For example, investing in sustainable irrigation may have a profound effect on the volume of water saved, but is only viable if water and financing is available. Water pricing aims at achieving the same water savings, but only works if the public accepts it. A third investment that increases subsurface water storage capacity will probably increase the water saved through the decreased effect of evaporation, but its long-term success also depends on the level of maintenance to prevent failures.

The key is to find mixes of the three investments that will result not only in the highest possible returns (cost–benefit analysis) in terms of water availability, but also a mix of water management investments that is capable of absorbing unexpected events; in other words, a mix that values uncertainty as part of the decision-making process (Brown and Carriquiry, 2007; Figge, 2004; Johansson et al., 2002; Perrot-Maitre, 2006).

8.2.10 Long-term versus short-term decisions

Depending on the timeframe and scope of an issue and the political time horizon, different uncertainties can have different relevancies to the decision-making process. The timeframe is of critical importance when looking at ambiguous information or irreversibilities. Long-term decisions are associated with capital investments in infrastructure projects that involve substantial fixed costs (costs that are independent of the scale or capacity of the project), and that require payment before the project can begin. Long-term investment decisions pertain to infrastructure design or land-use policy expected to exist over a long period. In many cases, it is difficult to reverse such decisions once implemented. For example, decisions to build reservoirs are easier to make than to reverse once the reservoirs exist. The challenge of long-term decision-making is to adequately consider future impacts given the uncertainty of future supply and demand conditions.

Consider decisions with respect to protecting from floods or reducing flood damage. The design of dykes or levies along the Mississippi River in the United States of America or along the coast of the Netherlands constitute examples of long-term decisions. No one can predict the degree of protection required for the future, even if such analyses are based on past hydrological events or future projections influenced by current knowledge of climate change. Hence, no matter what design is chosen there is a risk of failure. Questions that plague anyone making long-term decisions include what levels of risk are acceptable, and just how much more money, if any, should be spent on designs that reduce the costs of infrastructure expansion in the future, should future conditions warrant. Capacity-expansion models that include future uncertainties can provide guidance for making such decisions, but their results are also uncertain. Compared to long-term decisions, short-term decisions are much easier to make as their impacts are much more predictable. Short-term decisions typically involve changes in operating policies, whose performance depends on the long-term decisions made. For example, the proportion of storage in a reservoir that should be allocated to flood storage and the various beneficial purposes water serves (agricultural, domestic and industrial water supplies, hydropower, recreation, environment) – some of which are complementary, while others compete. These decisions may be influenced by recent hydrological and economic events or conditions, and in the case of farmers, forecast future crop market prices.

As with long-term decisions, short-term decisions made in uncertain environments also pose risks. But unlike many long-term risks, short-term risks are often more manageable and reducible. All those who face risks learn to live with or manage such risks. One approach to reduce individual risks is through insurance. Insurance is not always available, but when it is it can serve to reduce the economic consequences of flood events, or droughts leading to crop failures or famine, or disease brought on by excessive pollution. It serves as a way to mitigate the risks of economic loss. The problem for insurance companies is to determine their risks under changing climates – changes that are themselves not predictable. Index insurance avoids the need to make judgments on actual losses, say due to climate variability or human failure – a difficult task – as index insurance payments are made based on an independent indicator or measure that is correlated with outcomes, but not influenced by the insured individual (Brown and Carriquiry, 2007).

8.2.11 Policy uncertainty

The outcomes of any long term or short-term decisions depend in part on external factors. One such factor, which can have a significant influence on the success or effectiveness of any decision, is the set of policies or rules and regulations or laws established by public agencies. Changes in broader public policy can have substantial consequences on the potential effectiveness of a pollution control policy, or the success of a cascade of hydropower reservoirs in meeting energy targets or reducing damages resulting from floods. This source of uncertainty can be just as significant as the uncertainty resulting from natural events (Camerer and Weber, 1992).

8.2.12 Necessity and uncertainty of monitored data

As discussed in Chapter 6 of this report and Chapter 13 of WWDR3, there is a real need to commence global, systematic monitoring of the world's water resource systems and land-use patterns. Many signals suggest that climate is changing the rate, if not the nature, of hydrological processes taking place today in many regions. More research is needed to fully understand these events, their causes and the directions and rates of change. Improved hydrological and climate modelling and downscaling methods are badly needed by water resource planners and managers, who are facing problems that often need solving at sub-basin scales – spatial scales much smaller than those considered by global and even regional climate models.

But in addition to the need for more research on climate modelling, there is a need to learn more from the hydrological data recorded over the past century. During this period, humans had a major impact on land use and discharged a significant quantity of greenhouse gases into the atmosphere. Global CO_2 concentrations in the atmosphere increased by about 35% compared to levels at the beginning of the industrial revolution. This increase and the accompanying warming is highly likely to have had a measurable impact on the water cycle, which should be possible to detect by studying the hydrological records. As with climate and land cover changes, there is a need to monitor and better understand hydrological changes (e.g. soil moisture, frozen ground, nutrient dynamics, algal dynamics). Improved decision-making relies not only on better ways of modelling land-water-atmospheric interactions and the climate and its impacts at basin and watershed scales, but also continued monitoring and analyses of hydrological records (Murdoch et al., 2000; Naiman and Turner, 2000; Vörösmarty et al., 2000).

> "Unlike many long-term risks, short-term risks are often more manageable and reducible."

Monitoring and measuring are the only ways to determine the nature of changes occurring in the watersheds. This involves keeping records, decade after decade, and analysing those records. The fact that the probability distributions of water flows, storage volumes and their qualities and uses over space and time, are non-stationary increases the importance of continued monitoring, data management and analyses. Informed decision-making depends on observations of the systems being managed, understanding what those observations are telling us, and acting on this knowledge – continuously.

8.3 Using ecosystems to manage uncertainty and risk

History shows that pressures on water resources decrease ecosystem resilience and thereby increase ecosystem-related risks and uncertainties – reducing those pressures reduces this risk and uncertainty. Ecosystems can serve to reduce uncertainty, help manage risk, and achieve increased benefits from water security and water quality enhancement, recreation, hydropower, navigation, wildlife and flood control. Ecosystems include all the components involved in the water cycle, including land cover (vegetation) and soil functions in watersheds, wetlands and floodplains.

Ecosystems are used widely and have demonstrated their utility, particularly in reducing uncertainty associated with water quality, water extremes (drought and floods) and storage-related needs. Hard engineering approaches (see Chapter 5) have successfully reduced risks in rich nations, but at considerable capital and maintenance (and sometimes environmental) cost. Not all developing countries have the financial capital to adopt the same strategy. But as risks or priorities change (e.g. through climate change or urban expansion), physical infrastructure can be difficult and certainly expensive to modify or remove. This can limit adaptation options under changing conditions, and thereby increases risk. The use of built and natural infrastructure options should be considered together in order to manage medium to long-term risk.

History also shows that many risks associated with water arise through management that is blind to the ecosystem changes it drives, and their consequences for humans. Ecosystems are central to sustaining the water cycle, therefore, understanding this role provides a tool to assess how risks are generated and transferred. An inclusive, holistic and participatory approach to water policy and management permits identification of the full range of ecosystem services involved, where the risks are, who is vulnerable to them and why. Improved information can reduce, but never eliminate, uncertainty. A new paradigm is required and is already emerging (as indicated in Section 2.5), which shifts from regarding the ecosystem (environment) as an unfortunate but necessary cost of development to being an integral part of development solutions (Box 8.5).

Reducing the direct human demand for water will also reduce pressures on water, and thereby increase the sustainability of ecosystems, the delivery of ecosystem benefits, and therefore reduce risk. Other sections of this report address opportunities to reduce water footprints, including improving water use efficiency. At the implementation level, water managers may be called upon to actively manage various elements of the ecosystem and/or to inform those who have that responsibility. Identifying opportunities to proactively manage ecosystems to reduce uncertainty and manage risk involves a three-step process:

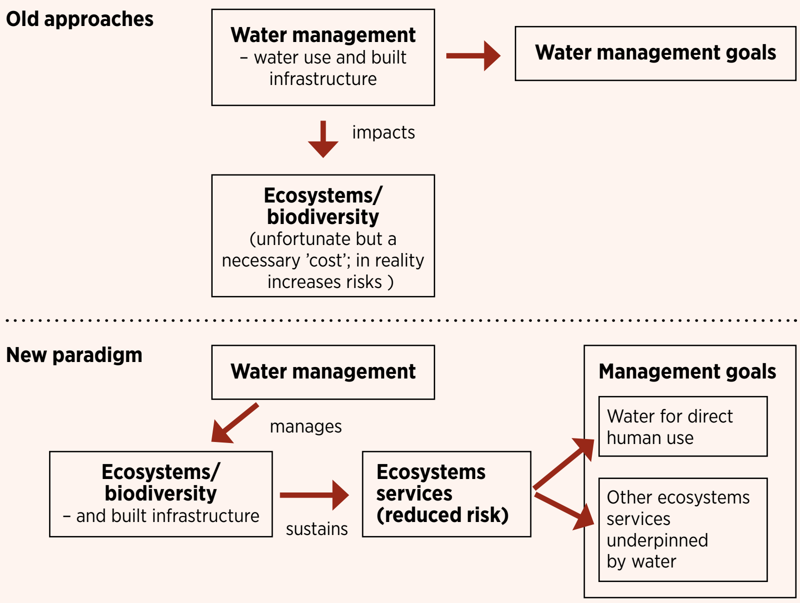
1. Identify the water management objectives as opposed to focusing on infrastructure (e.g. objectives are water storage or clean water, not dams or treatment plants).
2. Explore what ecosystems offer in terms of meeting the identified management objective(s) (e.g. storing water, reducing pollution), including through their conservation and/or restoration.
3. Reduce the uncertainties and risks involved in decisions by considering all ecosystem services directly involved or potentially impacted by various management options. This includes valuing multiple co-benefits, and examining trade-offs between them to determine desirable courses of action.

BOX 8.5

Changing paradigms for water management

Traditional approaches were aware that water management impacted ecosystems, but proceeded on the assumption that water use (for humans) was more important than the ecosystem (environment). The values of the full suite of benefits (services) provided by the ecosystem were therefore not included in decision-making. The result is increased overall risk with the ecosystem and its needs perceived as in conflict with human needs.

In the 'new paradigm' ecosystems are managed (together with built infrastructure) to achieve a water management goal of delivery of the full suite of required ecosystem services (including water quantity and quality), thereby reducing overall system risks. The ecosystem is seen not as a problem, but as a solution.



Ecosystem-based approaches harness the capacity of ecosystems as water infrastructure to improve resilience and deliver multiple water-related benefits more sustainably and often cost-effectively, thereby addressing risk. The term 'ecosystem' (or 'natural') infrastructure (see discussion in Section 5.1 concerning 'soft infrastructure') reflects an acknowledgement that the water-related services provided by ecosystems are analogous and complementary to those provided by conventional, engineered water infrastructure. Capital and operating costs of physical infrastructure should reflect the costs of lost ecosystem services. For example, the costs of drinking water treatment reflect this cost of ecosystem degradation (loss of clean water as an ecosystem service). There is a compelling cost–benefit case for public and/or private investment in green infrastructure, in part because of its significant potential as a means of adaptation to climate change (TEEB, 2009).

The global consequences of heavy reliance on hard-engineering solutions are beginning to be better understood in risk management terms. For example, Batker et al. (2010) present a convincing case study of the Mississippi Delta, where ecosystem restoration options offer significant economic gains to address the problem of risk increase in the delta, in particular disaster risk brought about by historical hard-engineered water management approaches (see Box 2.3 in Section 2.5). The policy of wholesale hard (physical) engineering approaches to water risk reduction has been debated between and among engineers and environmentalists for at least two decades. This discussion is increasingly subject to more rigorous science enabling the emergence of a less emotive, more impartial and balanced strategy towards risk (Box 8.6).

Demonstrations of the pitfalls of ecosystem-blind approaches make for a convincing case in themselves. But ecosystem solutions for dealing with uncertainty and risk are best demonstrated through practice, and there is currently a wholesale shift towards this approach. Some stakeholders in the business sector are leading by example (Box 8.7). For example, the World Resources Institute (WRI), working in conjunction with the World Business Council for Sustainable Development (WBCSD), has developed the 'Corporate

BOX 8.6

Rethinking physical infrastructure approaches

Vörösmarty et al. (2010) have presented human water security and biodiversity perspectives within the same spatial accounting framework. They used data depicting 23 stressors (drivers), grouped into four major themes representing environmental impact: catchment disturbance, pollution, water resource development and biotic factors. The results show that nearly 80% of the world's population is exposed to high levels of threat to water security, based on year-2000 figures, implying a much greater level of risk than indicated by previous assessments.

Developing countries, in particular, need to reduce water risk. In addition to 'hard' engineering solutions as well as when a lack of adequate levels of financial resources impedes appropriate infrastructure development, a sensible option is to employ ecosystem-based solutions, wherever possible. This also reduces medium-term risks and minimizes the possible need to eventually dismantle much of the physical infrastructure used to achieve sustainable balanced outcomes, once wealthy.

BOX 8.7

Ecosystem solutions for water quality risks

The use of natural infrastructure to protect water supplies, particularly drinking water for cities, is already widespread. For example, the Water Producer Programme, developed by the Brazilian National Water Agency, provides compensation to farmers to safeguard critical headwaters that supply water to 9 million people in the São Paulo metropolitan region. Success has spawned similar approaches in other regions of Brazil (Nature Conservancy, 2010). Likewise, the páramo grassland of Chingaza National Park, in the Colombian Andes, plays a crucial role in maintaining water supplies for 8 million people in the capital city, Bogotá, Colombia. An innovative public/private partnership has set up an environmental trust fund through which payments from the water company are transferred for managing the páramo sustainably, potentially saving the water company around US$4 million per year (Forslund et al., 2009). Box 21.5 in Chapter 21 describes how the potential for contamination by diffuse or point-source pollution, which represented a serious commercial risk to bottled water production, was dealt with by Nestlé S.A., France. A key mechanism for implementing these approaches is payments for ecosystem service schemes, whereby the users of a service (e.g. clean water) pay others to sustain its delivery. In 2006, the Convention on the Protection and Use of Transboundary Watercourses and International Lakes adopted recommendations on payments for ecosystem services (PES) as a part of integrated water resource management (IWRM) (UNECE, 2007).

Ecosystem Services Review', which helps companies to identify and measure the risks and opportunities arising from their impact and dependence on ecosystem services (WRI, Meridian Institute and WBCSD, 2008), within which water plays a prominent role. WBCSD (2011) also makes the case for ecosystem valuation as an integral part of business planning and corporate decision-making. There is a need to upscale such approaches across all relevant business activities.

The use or restoration of ecosystem infrastructure to sustain or improve water quality is already a widespread practice with a proven track record (Box 8.7). Using ecosystem infrastructure to manage risks associated with flooding is another area in which interest, practice and demonstrated feasibility are rapidly developing. Flood management also demonstrates clearly that water management involves risk transfer (Box 8.8).

Another relevant example is the successful experience of the Water Protection Fund (FONAG) in Ecuador, which is a water trust fund created to protect the watersheds that supply water to the Metropolitan District

BOX 8.8

Ecosystems and flood risk reduction

Catastrophic flooding is emerging as one of the most significant sources of increasing vulnerability due to three main factors: increasing human populations and infrastructure development in high flood risk areas (particularly megacities in developing countries); loss of wetlands services that regulate water flows; and most probably the increasing frequency and severity of extreme weather events under climate change.

Most modern flood management plans now include the use of floodplains and wetlands. Key services of these lands include their ability to rapidly absorb and slowly release (regulate) water, and to increase ecosystems resilience by regulating sediment transfer. These services alone account for some of the highest land/nature values thus far calculated, for example, US$33,000 per ha of wetlands for hurricane risk reduction in the United States of America (Costanza et al. 2008). Potential damage from storms, coastal and inland flooding and landslides can be considerably reduced by a combination of careful land-use planning and maintaining/restoring ecosystems to enhance buffering capacity. For example, a Viet Nam report (Tallis et al., 2008) shows that planting and protecting nearly 12,000 ha of mangroves cost US$1.1 million, but saved annual expenditures on dyke maintenance of US$7.3 million. Similarly, according to Emerton and Kekulandala (2003), the Muthurajawela Marsh, a coastal wetland in a densely populated area in North Sri Lanka, provides several more visible ecosystem services (agriculture, fishing and firewood), which directly contribute to local incomes (total value: US$150 per ha and per year), but the most substantial benefits, which accrue to a wider population are related to flood attenuation (US$1,907 per ha) and industrial and domestic wastewater treatment (US$654 per ha).

However, the economic arguments for natural infrastructure are not always clear-cut. In the case of the Maple River Watershed, US, Shultz and Leitch (2001) stated that ecosystem restoration delivered insufficient risk reduction.

China runs one of the largest payments for ecosystem services schemes worldwide: the Grain-to-Greens Programme to tackle soil erosion. Soil erosion is believed to be a principal cause of the extreme flooding that took place in 1998. Planting trees or maintaining pasture has restored 9 million ha of cropland on steep slopes. In addition to flood risk reduction, co-benefits include wildlife conservation, including positive impacts on Giant Panda habitats (Chen et al., 2009).

Managed risk transfer can be a solution to overall risk management. For example, London is very vulnerable to flooding, and its physical flood protection infrastructure is ageing rapidly. But flood risk managers are now committed to creating space for floodwater where possible through river restoration activities, for example, the London Rivers Action Plan (RRC, 2009). Dykes have historically been used in the upper catchment to protect agriculture, which has in effect diverted water more quickly towards London, increasing risks there. Based on the unsurprising fact that crops, livestock and agriculture infrastructure are less valuable than national monuments, major financial centres and high-priced housing, and the high population densities there, part of the flood management strategy now includes removing dykes, thereby restoring wetlands, and compensating farmers for their increased risks. Massive infrastructure maintenance costs and flood insurance premiums for city inhabitants are reduced in the process. Agricultural productivity is not significantly affected, and indeed could increase, except during the occasional extreme flood – providing evidence that restoring floodplains does not necessarily result in significant losses in longer-term agricultural output. The issue is clearly one of risk, not productivity, and the solution is to compensate where increased risk exposure occurs, thereby increasing overall benefits.

of Quito and surrounding areas, seeking to ensure the medium- and long-term availability of water (Box 8.9). FONAG's achievements have led to the creation of similar funds in other areas of Ecuador (Ambato, Riobamba, Cuenca, Loja and Espíndola) and elsewhere (Colombia and Peru) (Lloret, 2009).

Water-related ecosystem infrastructure involves all biological/ecological components of the water cycle, and is not limited to managing surface and groundwater water availability and quality. Examples of the role of forests in sustaining regional water balance, including avoiding tipping points, are provided in Chapter 4, Section 4.3. The role of land cover (vegetation) and soils in reducing hydrological risk illustrates the need to rethink water storage in ecosystem terms (Box 8.10).

Increasing uncertainty in water management is the result of less than optimal understanding of ecosystem functions and their impacts on ecosystem services in conjunction with serious gaps in data and monitoring. The historical focus of nature/environment interests and science on 'conservation' has contributed to this uncertainty. The objective is important in itself but the influence of conservation interests on water policy

BOX 8.9

Lessons learned in the implementation and operation of the Water Protection Fund (FONAG, Ecuador)

- The financial resources of FONAG are provided by direct users of water, part of whose payments goes towards the protection of water sources. The trust fund is fed by locally generated funds and is not dependent on foreign or government capital.
- Given the weak governance of natural resources, particularly water, the availability of long-term financial instruments is a guarantee that interventions and programmes to protect water resources are sustainable.
- The greatest impact is achieved by sustained and long-term programmes; thus a trust fund represents a way of achieving high-impact intervention.
- Given that the Fund's plans are developed in a participative way, they are always viewed as complementary to financing, resulting in the strong engagement of actors with the actions being taken.
- The rules of the Fund clearly specify the destination of investments and the maximum amounts that can be assigned to administration, current spending and other expenses, thus safeguarding the quantity and quality of investments.

Source: Lloret (2009, p. 6, Lessons Learned, with minor modification).

BOX 8.10

Rethinking water storage: Restoring soil functionality

Soil moisture is a major component of the water cycle. It contributes to groundwater and maintains surface vegetation and soil health. Soil ecosystems are biodiversity rich and support important and inter-dependent ecosystem services, including nutrient cycling, carbon storage, erosion regulation, water cycling and purification and in particular all agricultural production.

Loss of water degrades soil and drives desertification (see Section 4.5 and the CAR on Desertification, Land Degradation and Drought). Apart from changing rainfall patterns, the major cause of soil degradation is land-use practice, in particular soil disturbance (excessive tillage), pollution and loss of land cover (vegetation). Loss of soil moisture is a major risk challenge for agriculture and restoring water retention in soils is a key to sustainable agriculture. The Comprehensive Assessment of Water Management in Agriculture (Comprehensive Assessment of Water Management in Agriculture, 2007) concluded that improving rainfed agriculture, including rehabilitating degraded lands, is a major opportunity to increase agricultural production and achieve global food security. This issue is largely about managing moisture in soil ecosystems.

Conservation agriculture addresses soil water risks with three principles: minimal soil disturbance, permanent soil cover and crop rotation. Agricultural benefits include organic matter increase, in-soil water conservation and improvement of soil structure, and thus the rooting zone. Other enhanced ecosystem services include regulated soil erosion (reducing road, dam and hydroelectric power plant maintenance costs), water quality, air quality, carbon sequestration, biodiversity/nature benefits, and regulated water availability (including flood-risk reduction). Conservation agriculture holds tremendous potential for all sizes of farms, agro-ecological systems and zones. Using ecosystem-based management, it delivers profitable and sustainable agricultural production and greatly improved environmental benefits, including flood-risk reduction and regulated soil erosion. The approach is being adopted on a large scale, for example, in Brazil and Canada. It is also widely used to address water risks for food security in dryland areas where its multiple benefits offer significant advantages over high risk and capital-intensive irrigation options.

For further reading on conservation agriculture see the FAO website: http://www.fao.org/ag/ca/index.html.

(and hence in turn on nature conservation) is erratic and limited in areas where development priorities dominate, especially where water resources are limited. The past two decades have, however, brought a visible and welcome shift towards nature conservation interests, proposing solutions to water problems. Most major, international nature-based NGOs, for example, now see nature in a broader development context. This is particularly so for biodiversity, which as a topic has gravitated towards the central role it plays in delivering ecosystem services. But the science associated with this shift is lagging. Trends in species, populations and habitats remain the cornerstone of biodiversity monitoring, although they are increasingly used as proxies for ecosystem change. Limited data availability for the condition and extent of wetlands continues to constrain science – an important gap considering their hydrological functions. Advances have been made in the monitoring of desertification (a process driven principally by water availability) and its impacts on desert ecosystem services and the well-being of affected communities (e.g. UNCCD, 2011), but water quality data remain patchy at best. But the biggest gap in information relates to the continuing difficulties encountered in direct monitoring of many relevant ecosystem services. The most advanced ecosystem service monitoring areas remain confined to the direct benefits people receive, such as food and hydropower. Significant gaps exist in other key services, in particular nutrient cycling, sediment transfer and deposition (land formation, coastal erosion regulation), water regulation (including the role of evapotranspiration), and the capacity to tease out ecosystem influences within data on the economic and human impacts of water-related disasters (drought and flood mitigation services). Attempts to make the relevant connections between water, ecosystems and people are improving, but it remains essentially a process of storyline building, based on case studies and limited global data. The importance of the topic merits better resources to underpin the monitoring and improve understanding, and to reduce the current over-dependency on complicated, and occasionally controversial, science.

One characteristic of ecosystem infrastructure solutions is that they offer less opportunity for corruption. In the harsh realities of water management, this is likely a major reason why they have not been adopted more widely. But they are increasingly becoming part of the water management dialogue. Practitioners need to strengthen, in particular, the rigour of their economic assessments. Promoting ecosystem infrastructure as a panacea for managing all water risks must be avoided. It is best placed among a suite of options (including hard-engineered solutions) to address risk on a case-by-case basis, then assessed through transparent and participatory means, where better information reduces uncertainty. Such an approach will enable the most cost-effective, holistic and sustainable risk management strategies to emerge. Current evidence suggests that under these conditions ecosystem-based approaches will increasingly become the foundation of water security.

References

Aerts, J., Botzen, W., Bowman, M., Ward, P. and Dircke, P. 2011. *Climate Adaptation and Flood Risk in Coastal Cities.* Oxford/New York, Earthscan.

Aerts, J. C. J. H., W. Botzen, W., van der Veen, A., Krywkow, J. and Werners, S. 2008. Dealing with uncertainty in flood management through diversification. *Ecology and Society*, Vol. 13, No. 1, p. 41.

Aven, T. 2003. *Foundations of Risk Analysis: A Knowledge and Decision-oriented Perspective.* Chichester, UK, John Wiley.

Baggett, S., Jeffrey, P. and Jefferson, B. 2006. Risk perception in participatory planning for water reuse. *Desalination*, Vol. 187, No. 1–3, pp. 149–158.

Bardhan, P. 1993. Analytics of the institutions of informal cooperation in rural development. *World Development*, Vol. 21, No. 4, pp. 633–39.

Batker, D., de la Torre, I., Costanza, R., Swedeen, P., Day, J., Boumans, R. and Bagstad, K. 2010. *Gaining Ground – Wetlands, Hurricanes and the Economy: The Value of Restoring the Mississippi River Delta.* Tacoma, Washington DC, Earth Economics. http://www.eartheconomics.org/Page12.aspx.

Bedford, T. and Cooke, R. 2001. *Probabilistic Risk Analysis: Foundations and Methods.* Cambridge, UK, Cambridge University Press.

Berger, J. B. 1985. *Statistical Decision Theory and Bayesian Analysis.* New York, Springer.

Berstein, P. L. 1998. *Against the Gods: the Remarkable Story of Risk.* Chichester, UK, John Wiley.

Block, P. and Brown, C. 2009. Does climate matter? Evaluating the effects of climate change on future Ethiopian hydropower, planning for an uncertain future – monitoring, integration, and adaption. R. M. T. Webb and D. J. Semmens (eds) *Proceedings of the Third Interagency Conference on Research in the Watersheds: United States Geological Survey Investigations Report 2009-5049.*

Blumenfeld, S., Lu, C., Christophersen, T. and Coates, D. 2009. *Water, Wetlands and Forests. A Review of Ecological, Economic and Policy Linkages.* CBD Technical Series No. 47. Montreal/Gland, Switzerland, Secretariat of the Convention on Biological Diversity and Secretariat of the Ramsar Convention on Wetlands.

Bogardi J. J. and Kundzewic, Z. W. (eds) 2002. *Risk, Reliability, Uncertainty, and Robustness of Water Resources Systems*. UNESCO International Hydrology Series. Cambridge, UK, Cambridge University Press.

Brown, C. and Carriquiry, M. 2007. Managing hydro-climatological risk to water supply with option contracts and reservoir index insurance. *Water Resources Research,* Vol. 43, W11423.

Brugnach, M., Bolte, J. and Bradshaw, G. A. 2003. Determining the significance of threshold values uncertainty in rule-based classification models. *Ecological Modelling*, Vol. 160, No. 1–2, pp. 63–76.

Brugnach, M., Dewulf, A., Pahl-Wostl, C. and Taillieu, T. 2008. Toward a relational concept of uncertainty: about knowing too little, knowing too differently, and accepting not to know. *Ecology and Society*, Vol. 13, No. 2, p. 30. http://www.ecologyandsociety.org/vol13/iss2/art30/

Burton, I. 1996. The growth of adaptation capacity: practice and policy. J. Smith, N. Bhatti, G. Menzhulin, R. Benioff, M. I. Budyko, M. Campos, B. Jallow and F. Rijsberman (eds) *Adapting to Climate Change: An International Perspective.* New York, Springer-Verlag, pp. 55–67.

Callaway, J. M., Louw, D. B. and Hellmuth, M. E. 2008. Benefits and costs of measures for coping with water and climate change: Berg River Basin, South Africa. F. Ludwig, P. Kabat, H. van Schaik, and M. van der Valk (eds) *Climate Change Adaptation in the Water Sector.* London, Earthscan, pp. 191–212.

Camerer, C. and Weber, M. 1992. Recent developments in modelling preferences: uncertainty and ambiguity. *Journal of Risk and Uncertainty,* Vol. 5, No. 4, pp. 325–70.

Carpenter, S., Brock, W. and Hanson, P. 1999. Ecological and social dynamics in simple models of ecosystem management. *Conservation Ecology*, Vol. 3, No. 2, p. 4. http://www.consecol.org/vol3/iss2/art4/

Chen, X. D., Lupi, F., He, G. M. and Liu, J. G. 2009. Linking social norms to efficient conservation investment in payments for ecosystem services. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, Vol. 106, pp. 11812–17.

Coles, S. 2001. *An Introduction to Statistical Modeling of Extreme Values.* Springer Series in Statistics. London, Springer-Verlag.

Comprehensive Assessment of Water Management in Agriculture. 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture.* London/Colombo, Earthscan/International Water Management Institute (IWMI).

Cooke, R. M. 2009. A brief history of quantitative risk assessment. *Resources*, Vol. 172. Washington DC, Resources for the Future.

Cosgrove, W. and Rijsberman, F. 2000. *World Water Vision: Making Water Everybody's Business.* London, Earthscan.

Costanza, R., Pérez-Maqueo, O. M., Martínez, M. L., Sutton, P., Anderson, S. J and Mulder, K. 2008. The value of wetlands for hurricane protection, *Ambio*, Vol. 37, No. 4, pp. 241–248.

Covello, V. T. and Mumpower, J. 2001. Risk analysis and risk management: an historical perspective. S. Gerrard, R.K. Turner, I. Bateman (eds) *Environmental risk planning and management.* Cheltenham, UK, Edward Elgar.

Dessai, S. and van der Sluijs, J. P. 2007. Uncertainty and Climate Change Adaptation – a Scoping Study. Report NWS-E-2007-198. Department of Science Technology and Society, Copernicus Institute, Utrecht University.

DETR. 2000. *Guidelines for Environmental Risk Assessment and Management – Revised Departmental Guidance.* Prepared by the Institute for Environment and Health. London, The Stationery Office.

Downing, T. E., Olsthoorn, X. and Tol, R. S. J. 1999. *Climate, Change and Risk.* London, Routledge.

Duckstein, L. and Parent, E. 1994. Systems engineering of natural resources under changing physical conditions: a framework for reliability and risk. L. Duckstein and E. Parent (eds) *Natural Resources Management.* Dordrecht, The Netherlands, Kluwer.

Elshayeb Y. 2005. Overcoming uncertainties in risk analysis: trade-offs among methods of uncertainty analysis. I. Linkov and A. B. Ramadan (eds) *Comparative Risk Assessment and Environmental Decision Making.* NATO Science Series 38. Dordrecht, The Netherlands, Springer.

Emerton, L. and Kekulandala, L. D. C. B. 2003. *Assessment of the Economic Value of Muthurajawela Wetland.* Occ. Pap. Sri Lanka, International Union for Conservation of Nature (IUCN).

Fiering, M. B. 1982. Estimates of resilience indices by simulation. *Wat. Resour. Res.,* Vol. 18, No. 1, pp. 41–50.

Figge, F. 2004. *Managing Biodiversity Correctly – Efficient Portfolio Management as an Effective Way of Protecting Species.* Cologne, Germany: Gerling.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson L., Holling, C. S. and Walker, B. 2002. *Resilience and Sustainable Development: Building Adaptive Capacity in a World of Transformations.* Scientific Background Paper on Resilience for the process of the World Summit on Sustainable Development on behalf of the Environmental Advisory Council to the Swedish Government. Interdisciplinary Center of Natural Resources and Environmental Research, Stockholm University, Sweden.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L. and Holling, C. S. 2004, Regime shifts, resilience and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics,* Vol. 35, pp. 557–81.

Forslund, A., Malm Renöfält, B., Barchiesi, S., Cross, K., Davidson, S., Farrell, T., Korsgaard, L., Krchnak, K., McClain, M., Meijer, K. and Smith, M. 2009. *Securing Water for Ecosystems and Human Well-Being: The Importance of Environmental Flows.* Swedish Water House Report 24. Stockholm, Stockholm International Water Institute (SIWI).

http://www.siwi.org/documents/Resources/Reports/Report24_E-Flows-low-res.pdf

Frederick, K.D. and Major, D.C. 1997. Climate change and water resources. *Climatic Change*, Vol. 37, No. 1, pp. 7–23.

Frederick, K. D., Major, D. C. and Stakhiv, E. Z. 1997. Water resources planning principles and evaluation criteria for climate change: summary and conclusions. *Climatic Change,* Vol. 37, No. 1, pp. 291–313.

Ganoulis. J. G. 1994. *Engineering Risk Analysis of Water Pollution.* New York, VCH.

Giles, J. 2002. Scientific uncertainty: when doubt is a sure thing. *Nature,* Vol. 418, pp. 476–78.

Gladwell, M. 2000, *The Tipping Point: How Little Things Can Make a Big Difference.* New York, Little Brown.

Green, C., Nicholls, R. and Johnson, C. 2000. *Climate Change Adaptation: A Framework for Analysis and Decision-making in the Face of Risks and Uncertainties.* NCRAOA Report 24. London, Environment Agency.

Hall, K. 2003. An old problem in a new form. *International Water Power and Dam Construction 2003.* London, Global Trade Media, pp. 28–31.

Hamilton, L. C. and Keim, B. D. 2009. Regional variation in perceptions about climate change, *Int. J. Climatol.,* Vol. 29, No. 15, pp. 2348–2352. http://pubpages.unh.edu/~lch/Hamilton_climate_perception.pdf

Hashimoto, T., Loucks, D. P. and Stedinger, J. R. 1982. Robustness of water resource systems. *Water Resources Research,* Vol. 18, No. 1, pp. 21–26.

Hashimoto, T., Stedinger, J. R. and Loucks. D. P. 1982. Reliability, resiliency, and vulnerability criteria for water resource system performance evaluation. *Water Resources Research,* Vol. 18, No. 1, pp. 14–20.

Heltberg, R., Siegel, P. B. and Jorgensen, S. L. 2009. Addressing human vulnerability to climate change: toward a 'no-regrets' approach. *Global Environmental Change,* Vol. 19, No. 1, pp. 89–99.

Hobbs, B. F. 1997. Bayesian methods for analysing climate change and water resource uncertainties. *Journal of Environmental Management,* Vol. 49, No. 1, pp. 53–72.

Hoekstra, A. Y. and Chapagain, A. L. 2008. *Globalization of Water: Sharing the Planet's Freshwater Resources.* Oxford, UK, Blackwell Publishing.

Hoffman, B. 2011. Queensland warned of flood plain risk. *Sunshine Coast Daily,* 1 August 2011. http://www.sunshinecoastdaily.com.au/story/2011/08/01/we-develop-our-own-risk-expert/

Hoffmann-Riem, H. and Wynne, B. 2002. In risk assessment, one has to admit ignorance. *Nature,* Vol. 416, p. 123.

Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics,* Vol. 4, pp. 1–23.

Holling, C. M. 1986. The resilience of terrestrial ecosystems: local surprise and global change. W. C. Clark and R. E. Munn (eds) *Sustainable Development of the Biosphere.* Cambridge, UK, Cambridge University Press, pp. 292–317.

ISET (Institute for Social and Environmental Transition). 2010. Adaptive Strategies for Responding to Drought and Flood in South Asia. Website. Boulder, Colo., ISET International and ISET Nepal. http://www.i-s-e-t.org/index.php?option=com_content&view=article&id=44&Itemid=49

Johansson R. C., Tsur, Y., Roe, T. L., Doukkali, R. and Dinar, A. 2002. Pricing irrigation water: a review of theory and practice. *Water Policy,* Vol. 4, No. 2, pp. 173–99.

Kaplan, S. and Garrick, B. J. 1981. On the quantitative definition of risk. *Risk Analysis,* Vol. 1, No. 1, pp. 11–27.

Karamouz, M., Szidarovszky, F. and Zahraie, B. 2003. *Water Resources Systems Analysis.* Boca Raton, FL, Lewis Publishers.

Kasperson J. X., Kasperson, R. E., Pidgeon, N., Slovic, P. 2003. The social amplification of risk: assessing fifteen years of research and theory. N. Pidgeon, R. E. Kasperson, P. Slovic (eds) *The Social Amplification of Risk.* Cambridge, UK, Cambridge University Press.

Kasperson, R. E., Renn, O., Slovic, P., Brown, H., Emel, J., Goble, R., Kasperson, J. X. and Ratick, S. 1988. The social amplification of risk: a conceptual framework. *Risk Analysis,* Vol. 8, No. 2, pp. 177–87.

Keeney, R. L. and Raiffa, H. 1993. *Decisions with Multiple Objectives.* Cambridge, UK/New York, Cambridge University Press.

Keller, K., Yohe, G. and Schlesinger, M. 2008. Managing the risks of climate thresholds: uncertainties and information needs. *Climatic Change,* Vol. 91, pp. 5–10.

van 't Klooster, S., Pauw, P. and Aerts, J. C. J. H. 2011. Dealing with uncertainty through (participatory-) backcasting. J. C. J. H. Aerts, W. Botzen, Ph. Ward (eds) *Climate Adaptation and Flood Risk in Coastal Cities.* Abingdon, UK, Earthscan.

Knight, F. H. 1921. *Risk, Uncertainty, and Profit.* Boston, MA, Hart, Schaffner & Marx/Houghton Mifflin Company.

Kummu, M., Ward, P.J. de Moel, H. and Varis, O. 2010, Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. *Environ. Res. Lett.,* Vol. 5 (July–September).

Lenton, T. M., Held, H., Kriegler, E., Hall, J. W., Lucht, W., Rahmstorf, S. and Schellnhube, H. J. 2008. Tipping elements in the Earth's climate system. *PNAS,* Vol. 105, No. 6, pp. 1786–93.

Le Quesne, T. and Matthews, J. 2009. *Adapting Water Management: A Primer on Coping with Climate Change.* (WWF Water Security Series No. 3). Washington DC, World Wide Fund for Nature (WWF). http://assets.wwf.org.uk/downloads/water_management.pdf

––––. 2010. *Flowing Forward: Freshwater Ecosystem Adaptation to Climate Change in Water Resources Management and Biodiversity Conservation.* Working Note #28. Washington DC, World Wide Fund for Nature (WWF). http://assets.panda.org/downloads/flowing_forward_freshwater_ecosystem_adaptation_to_climate_change.pdf

Li, Y. P., Huang, G. H. and Nie, S. L. 2009. Water resources management and planning under uncertainty: an inexact multistage joint-probabilistic programming method. *Water Resources Management,* Vol. 23, pp. 2515–38.

Liu, A., Sty, T. and Goodrich, J. A. 2000. Land use as a mitigation strategy for the water-quality impacts of global warming: a scenario analysis on two watersheds in the Ohio River Basin. *Environmental Engineering and Policy,* Vol. 2, No. 2, pp. 65–76.

Lloret, P. 2009. Water Protection Fund (FONAG). *Circular of the Network for Cooperation in Integrated Water Resource Management for Sustainable Development in Latin America and the Caribbean,* No. 29. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/drni/noticias/circulares/2/34862/Carta29in.pdf

Loewenstein, G., Rick, S. and Cohen, J. D. 2008. Neuroeconomics. *Annu. Rev. Psychol.,* Vol. 59, pp. 647–72.

Lofstedt, R. E. 2003. A European perspective on the NRC 'Red Book,' risk assessment in the Federal Government: managing the process. *Human and Ecological Risk Assessment,* Vol. 9, No. 5, pp. 1327–35.

Loucks, D. P. and van Beek, E. 2005. *Water Resources Systems Planning and Management.* Paris, UNESCO.

MA (Millennium Ecosystem Assessment). 2005. *Ecosystems and Human Well-Being: Wetlands and Water Synthesis.* Washington DC, World Resources Institute (WRI).

Males, R. M. 2002. *Beyond Expected Value: Making Decisions Under Risk and Uncertainty.* Alexandria, Va., US Army Corps of Engineers, Institute for Water Resources. http://www.iwr.usace.army.mil/docs/iwrreports/02r4bey_exp_val.pdf

Marien, M. 2002. Futures studies in the 21st century: a reality-based view. *Futures,* Vol. 34, pp. 261–81.

Marris, C., Langford, I., Saunderson, T. and O'Riordan, T. 1997. Exploring the 'psychometric paradigm': comparisons between aggregate and individual analyses. *Risk Analysis,* Vol. 22, No. 4, pp. 665–9.

Martin, R. 2002. *The Responsibility Virus: How Control Freaks, Shrinking Violets – and the Rest of us – Can Harness the Power of True Partnership.* New York, Basic Books.

Mays, L. W. 1996. The role of risk analysis in water resources engineering. *Water Resources Update,* Vol. 103, pp. 8–11.

Miller, K. and Yates, D. 2006. *Climate Change and Water Resources: A Primer for Municipal Water Providers.* Denver, CO, Awwa Research Foundation (AwwaRF)/University Cooperation for Atmospheric Research (UCAR).

Morgan, M. G. and Henrion, M. 1990. *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis.* Cambridge, UK, Cambridge University Press.

Murdoch, P. S., Baron, J. S. and Miller T. L. 2000. Potential effects of climate change on surface-water quality in North America. *J. Am. Water Resour. Assoc.,* Vol. 36, No. 2, pp. 347–66.

Naiman, R. J. and Turner, M. G. 2000. A future perspective on North America's freshwater ecosystems. *Ecological Applications,* Vol. 10, No. 4, pp. 958–70.

Nature Conservancy. 2010. *South America: Creating Water Funds for People and Nature.* Website. Arlington, Va., The Nature Conservancy. http://www.nature.org/wherewework/southamerica/misc/art26470.html

NOAA (National Oceanic and Atmospheric Administration). 2009. *Restoration Economics: Risk and Uncertainty in Environmental Restoration Programs.* Washington DC, US Department of Commerce.

NRC (National Research Council). 2000. *Risk Analysis and Uncertainty in Flood Damage Reduction Studies Committee on Risk-Based Analysis for Flood Damage Reduction.* Washington DC, National Academies Press.

Palmer, M. A, Reidy Liermann, C. A., Nilsson, C., Flörke, M., Alcamo, J., Lake, P. S. and Bond, N. 2008. Climate change and the world's river basins: anticipating management options. *Frontiers in Ecology and the Environment,* Vol. 6, pp. 81–9.

Perrot-Maître, D. 2006. *The Vittel Payments for Ecosystem Services: a 'Perfect' PES Case?* London, International Institute for Environment and Development (IIED).

Pindyk, R. S. 2007. Uncertainty in environmental economics. *Review of Environmental Economics and Policy,* Vol. 1, No. 1, pp. 45–65.

Plate, E. J. and Duckstein, L. 1988. Reliability based design concepts in hydraulic engineering. *Wat. Resour. Bull.,* Vol. 24, pp. 234–45.

Policy Research Corporation. 2009. *Netherlands.* Brussels, European Commission. http://ec.europa.eu/maritimeaffairs/climate_change/netherlands_en.pdf

Rahmstorf, S. and Ganopolski, A. 1999. Long-term global warming scenarios computed with an efficient coupled climate model, *Climatic Change,* Vol. 43, pp. 353–67.

Rayner, S. 1992. Cultural theory and risk analysis. S. Krimsky and D. Golding (eds) *Social Theories of Risk.* Westport, Conn., Praeger.

RRC (River Restoration Centre). 2009. *The London River Action Plan.* London, RRC.

Saunders, J. F. and Lewis, W. M. 2003. Implications of climatic variability for regulatory low flows in the South Platte River basin, Colorado. *J. Am. Water Resour. Assoc.,* Vol. 39, pp. 33–45.

Shultz, S. D. and Leitch, J. A. 2001. *The Feasibility Of Wetland Restoration To Reduce Flooding In The Red River Valley: A Case Study Of The Maple River Watershed, North Dakota.* Agribusiness & Applied Economics Report No. 23597. North Dakota State University, Department of Agribusiness and Applied Economics.

Simonovic, S. P. 2008. Managing Water Resources: Methods and Tools for a Systems Approach. London, Earthscan.

Slovic, P. 1992. Perception of risk: reflections on the psychometric paradigm. S. Krimsky and D. Golding (eds) *Social theories of risk.* New York, Praeger, pp. 117–52.

Slovic, P., Finucane, M, Peters, E. and MacGregor, D. G. 2004. Risk as analysis and risk as feelings: some thoughts about affect, reason, risk, and rationality. *Risk Analysis,* Vol. 24, No. 2.

Stuip, M. A. M, Baker, C. J. and Oosterberg, W. 2002. *The Socio-economics of Wetlands.* Wageningen, The Netherlands, Wetlands International and the Dutch Institute for Inland Water Management and Waste Water Treatment (RIZA).

Tallis, H., Kareiva, P., Marvier, M. and Chang, A. 2008. An ecosystem services framework to support both practical conservation and economic development. *Proceedings of the National Academy of Sciences of the United States of America (PNAS),* Vol. 105, No. 28, pp. 9457–64.

TEEB (The Economics of Ecosystems & Biodiversity), 2009. *TEEB Climate Issues* Update. Geneva, United Nations Environment Programme (UNEP). http://www.teebweb.org/InformationMaterial/TEEBReports/tabid/1278/language/en-US/Default.aspx.

Tversky, A. and Kahneman, D. 1974. Judgment under uncertainty: heuristics and biases. *Science,* Vol. 85, pp. 1124–31.

UNCCD (United Nations Convention to Combat Desertification). 2011. *Scientific Review of the UNCCD Provisionally Accepted Set of Impact Indicators to Measure the Implementation of Strategic Objectives 1, 2 and 3.* White-Paper – Version 1, Unpublished draft. New York, UNDP Bureau for Crisis Prevention and Recovery.

––––. 2004. *Reducing Disaster Risk: A Challenge for Development.* New York, UNDP Bureau for Crisis Prevention and Recovery.

UNDRO (United Nations Disaster Relief Organization). 1991. *Mitigation of Natural Disasters: Phenomena, Effects, and Options. A Manual for Policy Makers and Planners.* New York, United Nations, Office of the Disaster Relief Coordinator.

UNECE (United Nations Economic Commission for Europe). 2007. *Recommendations on Payments for Ecosystem Services in Integrated Water Management.* New York/Geneva, United Nations. http://www.unece.org/index.php?id=11663

UNESCO (United Nations Economic, Scientific and Cultural Organization). 2005. *The Precautionary Principle.* Paris, UNESCO World Commission on the Ethics of Scientific Knowledge (COMEST).

UN-Water. 2006. *Coping with Water Scarcity: A Strategic Issue and Priority for System-wide Action.* UN-Water Thematic Initiatives. Geneva, UN-Water.

van Aalst, M., Hellmuth, M. and Ponzi, D. 2007. *Come Rain or Shine: Integrating Climate Risk Management into African Development Bank Group Operations.* Tunis, Tunisia, African Development Bank.

van Notten, P. W. F. 2005. *Writing on the Wall. Scenario Development in Times of Discontinuity,* Boca Raton, FL, Dissertation.com.

––––. 2006. Scenario development: a typology of approaches. *Think Scenarios, Rethink Education.* Paris, OECD. http://www.oecd.org/dataoecd/27/38/37246431.pdf

Vörösmarty, C. J., Green, P., Salisbury, J. and Lammers, R. B. 2000, Global water resources: vulnerability from climate change and population growth, *Science,* Vol. 289, No. 5477, pp. 284–8.

Vörösmarty C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Reidy Liermann, C. and Davies, P. M. 2010. Global threats to human water security and river biodiversity. *Nature,* Vol. 467, pp. 555–61.

Walker, B., Holling, C. S., Carpenter, S. R. and Kinzig, A. 2004. Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society,* Vol. 9, No. 2, p. 5. http://www.ecologyandsociety.org/vol9/iss2/art5/

Walker, B. and Meyers, J. A. 2004. Thresholds in ecological and social-ecological systems: a developing database. *Ecology and Society,* Vol. 9, No. 2, p. 3. http://www.ecologyandsociety.org/vol9/iss2/art3.

Walker, W. E., Harremoës, P., Rotmans, J., van der Sluijs, J.P., van Asselt, M. B. A., Janssen, P. H. M. and von Krauss, M. P. K. 2003. Defining uncertainty: a conceptual basis for uncertainty management in model based decision support. *Integrated Assessment,* Vol. 4, No. 1, pp. 5–17.

Wardekker, J. A., van der Sluijs, J. P., Janssen, P. H. M., Kloprogge, P. and Petersen, A. C. 2008. Uncertainty Communication in environmental assessments: views from the Dutch science-policy interface. *Environmental Science & Policy,* Vol. 11, No. 7, pp. 627–641. http://dx.doi.org/10.1016/j.envsci.2008.05.005

WBCSD (World Business Council for Sustainable Development). 2011. *Guide to Corporate Ecosystem Valuation: A framework for improving corporate decision-making.* Geneva, WBCSD.

Willows, R. I. and Connell, R. K. (eds) 2003. *Climate adaptation: Risk, uncertainty and decision-making.* UKCIP Technical Report. Oxford, UK Climate Impacts Programme (UKCIP).

Wolt, J. D. and Peterson, R. K. D. 2000. Agricultural biotechnology and societal decision-making: the role of risk analysis. *AgBioForum,* Vol. 3, No. 1. http://www.wbcsd.org/DocRoot/iv9e2wIURXHjP8in0RVN/WBCSD_Guide_CEV_April_2011.pdf

WRI (Water Resources Institute), Meridian Institute and WBCSD. 2008. *Corporate Ecosystem Services Review: Guidelines for Identifying Business Risks and Opportunities Arising from Ecosystem Change.* Geneva, WRI/WBCSD/Meridian Institute. http://pdf.wri.org/corporate_ecosystem_services_review.pdf

Yoe, C. E. 1996. *An introduction to risk and uncertainty in the evaluation of environmental investments.* IWR Report 96-R-8, prepared for the US Army Corps of Engineers. Alexandria, VA, Institute for Water Resources.

CHAPTER 9

Understanding uncertainty and risks associated with key drivers

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Managing water is managing risks old and new. Water management has always included managing risk and a significant body of knowledge exists about the management of the water cycle and its physical processes. Water management is also a cross-sectoral activity in which water managers are responsible for meeting the requirements of different economic sectors and the environment while caring for equity issues. This is not an easy task. The water system is dynamic and is characterized by large spatial and temporal variability in precipitation and runoff, with water-related risks such as floods and droughts. The allocation frameworks that regulate the distribution of water among different uses do not always reflect physical realities including the inherent variability in resource availability. Moreover, dynamics within sectors often create new and unexpected demands on water resources, increasing stress on its capacity to supply water for society and the environment.

The United Nations World Water Assessment Programme (WWAP) is currently undertaking a project to develop potential scenarios for the world's water resources and their use up to 2050. The last global water scenarios were published over ten years ago (Cosgrove and Rijsberman, 2000), and although they took into account most uncertainties and risks known at that time, they did not consider climate change. Furthermore, demography, technology, politics, societal values, governance and law are demonstrating accelerating trends or disruptions. Linkages are being made with other scenario processes being undertaken at the global level, such as new global environment scenarios (Global Environment Outlook 4) and the new Intergovernmental Panel on Climate Change (IPCC) scenarios on climate change. This chapter reflects findings to date.[1]

9.1 Possible evolution of key drivers

Traditionally, analysis of past climate coupled with stochastic analysis has provided a fairly reliable basis for examining the water cycle with its hydrological extremes. Historical climatic and hydrological information often forms the starting point for water managers and extrapolations of the past are routinely conducted in order to simulate future hydrological conditions. However, projected pressures on water resources lie outside the control of water managers. These can significantly affect the balance between water demand and supply – sometimes in uncertain ways – and thus create new risks for water managers and users. Such increasing uncertainties and risks necessitate a different approach to water management strategies.

The first phase of the WWAP World Water Scenarios Project has undertaken research on ten drivers of change. The relevance of each of these drivers varies in different regions of the world.

Water stress and sustainability are functions of the available water resources and their withdrawal and consumption. Both resources and consumption are variables that depend on many factors. Drivers that directly impinge upon water stress and sustainability are the ecosystem, agriculture, infrastructure, technology, demographics and economy. The ultimate drivers, *governance, politics, ethics* and society (values and equity), *climate change* and *security* exert their effect mostly through their impacts upon the proximate drivers. Experts in each of the fields covered by the drivers were asked to read one of the ten research reports and give their views about the future developments that were identified. Some participated in an exercise where they were asked to identify the relative importance of the developments and when it was likely they would occur. Others completed a survey in which they indicated which developments were more likely to occur, and when. The following text highlights developments considered most important or likely to occur.

9.1.1 Water resources: Surface water, groundwater and ecosystems

Any study of strategy, planning, design, operation and management of water resources systems must take as its basis *variability* of quantity and quality in water sources and supply systems. The new dimension that now must be considered is the importance of these possible variables and the uncertainty of the limits of their variability.

Expert survey participants in the WWAP World Water Scenarios Project ranked increases in water productivity in agriculture as the *most important* development affecting water. Water productivity for food production increased by nearly 100% between 1961 and 2001. Participants estimated that it would likely increase another 100% by 2040. They further estimated that rainfed agriculture globally will likely yield an average of 3.5 tonnes per ha of grain by around 2040.

The *second most important* development affecting water was the percentage of land area subject to droughts. The participants estimated that this could increase by at least 50% for extreme events, 40% for severe droughts and 30% for moderate ones by the 2040s.[2] Water availability issues were among the *most likely* developments to occur before 2050.

The participants considered global water withdrawals likely to increase by 50% from 2000 levels before 2020, with a probable 10% reduction in annual mean streamflows by 2030 in most of the populated areas of the world. By the beginning of the 2030s, groundwater recharge rates could be reduced by 20% in areas already suffering from water stress in 2010. The participants further considered that global agricultural trade by 2020 could contain the virtual water equivalent to 20% of the total water withdrawn globally for food production.

Solutions for the monitoring and management of water availability were seen as unlikely to occur in the short term. Conjunctive groundwater and surface water management were seen as unlikely to occur almost everywhere before the 2040s. This was also the case for management of withdrawals from aquifers to ensure they do not exceed the mean recharge rates of the previous decade.

The participants predicted that the Pacific Decadal, El Niño-Southern and North Atlantic Oscillations would likely be understood by the 2020s, and hence included in climate forecasting models. Recognition of the context of non-stationary climates and hydrological and anthropogenic forcing in all water management planning and operations was seen as likely to follow at the beginning of the 2030s.

Desalination was not viewed as a likely solution to water availability before the end of the 2040s. It was considered likely that desalination could produce 25% of

"The survey participants expected that a strong, effective universally binding international agreement to combat climate change would likely be in place by 2040; this was viewed as an event of high importance."

the drinking water for cities by the end of the 2040s, and 5% of water used for food production by the middle of the century. The slow adoption rate of desalination technologies was also reflected in responses to the consultations on Agriculture, Economy and Technology.

The loss of species diversity was viewed as both important and likely to occur by the beginning of the 2030s. Diversity of freshwater biological species could be significantly reduced as early as the beginning of the 2020s, and was seen as likely by 2030 due to higher temperatures, reduced flows, atmospheric carbon dioxide and increased nitrogen caused by climate change. Organisms with strong adaptive capacity to extreme environmental variability could also increasingly dominate ecosystems by the beginning of that decade. The implementation of appropriate countermeasures to limit biodiversity and loss and reduce the rate of loss by 50% was seen as likely to occur by the beginning of the 2040s. However, the participants considered it unlikely that the presence and spread of water-borne invasive alien species could be brought under control before 2050.

9.1.2 Agriculture

The most important development related to water resources according to participants was increasing water withdrawals for agriculture. Withdrawals were seen as likely to increase from the current level of approximately 3100 billion m^3 to 4500 billion m^3 per year by 2020, or more likely, 2030. In several regions of the world – South Asia, Latin America and Africa, in particular, sub-Saharan Africa – availability of water in these volumes is not physically possible. In other regions, the significant investment in infrastructure required for storage is not economically possible for many countries concerned.

The second most important ranked development was deforestation. Regions might seek to increase their agricultural areas by continuing to expand deforestation, albeit more slowly. Participants viewed this development as more likely to occur than the slowing of expansion of agricultural lands as a result of ecological concerns.

Looking at *probable* developments, the probability was seen that fertilizer prices would continue to track energy prices. If energy prices continue to rise, the cost of produce will also rise unless offset by other measures. Another probability was that investments in infrastructure would improve the production potential of rainfed farming (e.g. by improving rainwater collection and storage systems) by 2020. Such a development would make more efficient use of available land and water.

9.1.3 Climate change and variability

Climate change will affect the hydrological cycle and hence the availability of water for its users. It is expected that extreme water-related events such as floods and droughts will occur more frequently and with greater intensity (Bates et al., 2008). Extrapolations using historical data are no longer valid for these events – as for the hydrological cycle as a whole – which increases uncertainty about the future. Furthermore, the spatial resolution of global climate change models is relatively coarse. As a result, conversion to the more detailed scale necessary for water managers can prove difficult. The problem is compounded by the fact that these projections are not available at the jurisdictional level (state and local), or at the river basin level where much of water resources planning takes place.

The *important* developments for this driver are related to water availability. The survey participants estimated that the number of people at risk from water stress was likely to reach 1.7 billion before 2030 (before 2020 at the earliest), and 2.0 billion by the beginning of the 2030s. This number was not likely to reach 3.2 billion before 2050. This is roughly consistent with, though possibly slightly ahead of, the IPCC SRES scenarios (Nakicenovic, 2000).

Another important development was the increase in delta land vulnerable to serious flooding. This could expand by 50% and was seen as likely to occur by the beginning of the 2040s.

These events could have a significant impact on agriculture. Inter-annual freshwater shortages combined with flooding were seen as likely to reduce total global crop yields by 10% by the 2040s.

Another important development was the potential for a worldwide rise in living standards and population growth to greatly increase the demand for energy, causing a 20% increase in GHG emissions. This was considered likely by the beginning of the 2030s. Alternative energy technologies and solutions were likely to emerge more significantly around this time. Battery-powered electric cars could have a 30% share of the world automobile market by the 2030s. Wind power could generate 20% of the world electricity demand towards the end of the same decade. By the 2040s, 30% of the world power consumption could be connected to 'smart' power grids, while hydrogen fuel cells could power 20% of the world automobile market during the same decade. Carbon capture and storage could be used in 50% of all new fossil power plants, most likely after 2050, with existing plants being retrofitted or closed.

The survey participants expected that a strong, effective universally binding international agreement to combat climate change would likely be in place by 2040; this was viewed as an event of high importance.

The positive development with *earliest likelihood* of occurring is an extensive well-planned and financed multi-national campaign to support public education on the facts, causes, effects and costs of climate change, by the beginning of the 2020s. Increased public information and knowledge transfer about climate-related issues are likely to occur after this. For example, indisputable global precipitation and temperature changes could be reported publicly in the 2020s, with effective international coordination in place covering activities in climate analysis, mitigation and adaptation, and continual exchange of related up-to-date data, knowledge and experience by the 2030s. The 2030s will also likely see the integration of funding for climate change adaptation into funding for adaptive water management – a priority for water-reliant socio-economic sectors.

9.1.4 Infrastructure

Aging water infrastructure, lack of data and deteriorating monitoring networks represent major risks for the future in nearly all regions.

Survey participants viewed access to potable water and appropriate sanitation facilities as the *most important* developments in this regard. They considered that 90% of the global population would likely have reasonable access to a reliable source of safe drinking water by the beginning of the 2040s. Their view that the beginning of the 2030s would see the routine use of nanofilters in the treatment of potable water in over 30 countries may also have influenced this appraisal. The technology survey provided a similar time horizon for the roll out of this technology: it was considered likely that economically viable nanotechnology (such as carbon nanotubes) could yield new and effective membranes and catalysts useful in desalination and pollution control by 2030. The participants further considered that 90% of the global population would most likely have reasonable access to appropriate sanitation facilities towards the end of the 2040s.

A second important development was the annual inspection of all dams and dykes over 50 years old, and all those with significant risks from hazards for structural soundness. This was estimated most likely to begin in the 2030s. The development of emergency evacuation plans with clear implementation responsibility for these dams and dykes was also considered most likely to occur in the 2030s. This is particularly relevant as the increased siltation of dams due to climate change and deforestation could shorten the estimated remaining lifetime of a significant number of large dams by 30%. This development was also viewed as important and most likely to occur within the same timeframe as the previous developments.

Investments in infrastructure were considered also to be of importance. Income for water services (tariffs, taxes and transfers) covering all operating costs and depreciation of infrastructure globally were considered likely to occur at the beginning of the 2040s. This was also the case for the write-off of external debt of low-income countries, freeing funds for investment in water infrastructure.

Inland navigation needs would continue to influence river operations and flow allocations. The 2020s would likely see national water planning taking into account the need to provide appropriate environmental flows in the regulation of water infrastructure.

With the the beginning of the 2030s would likely come robots to remotely and reliably mend underground pipes in at least ten countries, and the use of chemical, biological, radiological and nuclear (CBRN) sensor networks to monitor hazardous incidents in water systems. Participants also estimated that remote sensing technologies and GPS could be used to supplement local water resource monitoring systems and other technologies, by the 2030s, to identify, map and explore underground infrastructures whose location was unknown or forgotten.

9.1.5 Technology

Survey participants expected most of the largest water consumers using products to conserve water between 2020 and 2030. These include pressure-reducing valves, horizontal-axis clothes washers, water-efficient dishwashers, grey-water recycling systems, low-flush tank toilets and low-flow or waterless urinals.

Inexpensive technologies for water desalination in large volumes, enabling nearly everyone within 100 miles (160 km) of coastlines to have water for their drinking and industrial water needs, were considered likely by 2020 with increasing likelihood by 2030. This was linked to economically viable nanotechnology (such as carbon nanotubes), which could yield new and effective membranes and catalysts useful in desalination and pollution control by removing heavy metal and other dissolved pollutants from water. Participants saw this as likely between 2020 and 2030. These dates probably reflect an appreciation of the delays in adopting and building systems with the new technology.

The widespread adoption of a well-known technology, rainwater harvesting, combined with new, simple and cheap ways of purifying the collected water was also considered likely between 2020 and 2030. The same likelihood was accorded to the use of affordable technology by agriculturists to capture real-time data on their crops and soil moisture, enabling them to make informed decisions on efficient irrigation schedules. Both would help increase the efficiency of land and water use.

9.1.6 Demography

Population dynamics including growth, age distribution, urbanization and migration lead to increased pressures on freshwater resources through greater demand for water and higher pollution levels.

Unsurprisingly, overall world population size figured as an *important* issue for developments in this section. Survey participants felt that the world population could reach 7.9 billion by 2034, 9.15 billion at the beginning of the 2050s, and 10.46 billion beyond 2050. This is in keeping with the UN Population Division's 2008 Revision medium variant, which estimated a population of 9.1 billion by 2050 (UNDESA, 2009).

Population growth could overwhelm past gains in water and sanitation accessibility. Participants (mainly demographers) considered that by the 2030s, population growth in the majority of developing countries could reduce the percentage of those with improved access to water supply and sanitation achieved since 1990 by 10%.

Education and employment of women was seen as a development influencing fertility, particularly in least developed countries. By the 2030s, the rise in levels of women's education and employment in a majority of least developed countries could cause a significant decline in fertility levels.

Efforts to reduce mortality in least developed countries were considered as developments with the *earliest likelihood*. In the group of 58 countries for which HIV/AIDS prevalence is above 1% and/or whose HIV population exceeds 500,000, most could achieve anti-retroviral treatment coverage for people living with HIV/AIDS of 60% or more by the 2020s. In the same decade the number of interventions to prevent mother-to-child transmission of HIV in these countries could reach an average of 60%. The coverage level for both interventions was 36% in 2007.

The combined global deaths per year from diarrhoeal diseases and malaria could decrease to 1.54 million or less before 2030 (compared to 2.53 million in 2008), and to 710,000 or less before 2040.

The infant mortality rate was seen as likely to drop. The average estimated mortality rate in 2005–2010 in less developed countries was 78 deaths per 1,000 live births.[3] By 2030 the rate was projected to drop in 60 developing countries to 45 deaths per 1,000 live births. Expected successes in overcoming these challenges could explain why participants estimated that all developing countries have a life expectancy of 70 years or more by the 2040s.

Developments that could diminish longevity were seen as possible. By the 2030s, the worsening of the epidemiological environment with regards to the spread of pandemics, re-emerging pathogens and the evolution of drug-resistant diseases could prevent the average world life expectancy from growing above 75.5 years. By the late 2030s, delayed impacts of obesity could act against increasing life expectancy beyond 75.5 years.

Growth in urban population was also deemed important. By the end of the 2030s 70% of the world population was seen as likely to become urban. The proportion of the world population living in slums was likely to decrease just to 25% by the end of the 2040s, from 33% today.

The proportion of world population living in coastal areas could reach 75% in the 2030s, increasing from 60% in 2010. The number of migrants due to the impacts of climate change was likely to reach 250 million in the 2040s. Migration following natural disasters and conflict-based events often occurs principally to coastal urban areas, including large peri-urban slums with little or no access to basic services and increased risk exposure to disease and epidemics.

9.1.7 Economy and security

Survey participants on the economy and security gave almost equal importance to two possible developments.

First, the demand for water in developing countries could increase by 50% over current 2011 levels. Participants considered this likely to happen between 2020 and 2030. This reinforces the issues raised by the participants who reviewed agricultural developments.

Second, over 40% of countries could experience severe freshwater scarcity by 2020. This would occur mostly in low-income countries or regions in sub-Saharan Africa and Asia. It was considered more *likely* that unequal access to water would create new economic polarities, between 2020 and 2030. Such economic polarities would increase the dangers of political unrest and consequent conflict.

> “A water footprint measure will likely be available and published widely on an annual basis between 2020 and 2030.”

A water footprint measure will likely be available and published widely on an annual basis between 2020 and 2030 (e.g. in 2030 the ecological footprint is expected to be around twice the size of the Earth’s surface). Such a tool would provide useful information to decision-makers, although the question remains as to whether they will have the resources and will to respond appropriately. Several types of cost-effective desalination or other technologies could be widely available and increase safe water supply by 20% globally between 2020 and 2030. This applies to drinking water and water for industrial use, but desalinated water will probably remain prohibitively expensive except for high value crops or new, more intense types of food production.

9.1.8 Governance

Many survey participants saw the failure of urban water supply infrastructure in many cities as important (underscoring the need to upgrade urban water systems). This could happen in more than two-dozen major cities by 2030. That this item appears so high in a review on governance indicates that participants feel that urban water system governance is badly in need of attention.

‘The development of online forums on water issues including local government and civil society was also considered important, reducing the asymmetry of information between user, provider and policy-maker. Networked coordination at the national level to share information and best practices between local water agencies was similarly viewed as important and likely to be achieved in at least 95% of countries between 2020 and 2030. Clearly, public consultation and information sharing are considered key factors with a fair degree of likelihood.

The adoption of an international convention specifically dedicated to groundwater was considered important, reflecting the lack of attention to groundwater in the past. Yet while participants thought it important, it was considered likely to occur only by 2030, probably reflecting the delays in ratification of the 1997 United Nations Convention on Non-Navigational Uses of International Watercourses (which has received 24 ratifications as of October 2011).

9.1.9 Politics

The survey participants on politics had similar views on the *importance* of establishing and following transparency and participation procedures in matters of water governance. However, they saw little likelihood that this would take place in at least 120 countries by 2020–2030. They also saw as important the number of people living in insecure or unstable countries that run a significant risk of collapse. Two billion people were living in such conditions in 2010, according to the Failed States Index 2010 – a collaborative between the Fund for Peace and *Foreign Policy* that uses 12 indicators of state cohesion and performance to assess the vulnerability of 177 states.[4] That this could be reduced to less than 1 billion people by 2030 was viewed as unlikely. As noted earlier, water (and related food and energy) scarcity could have a major negative impact on achieving this objective. In fact, participants saw a much greater likelihood that social instability and violence could spread to most states faced with chronic water scarcity.

Politics respondents considered that resistance within government and from vested interests could keep governments from becoming more participatory, flexible and transparent, leading to further mistrust and/or increased activism. The group thought it likely that at least 100 countries would fall into this category between 2020 and 2030. They thought it almost as likely that most people could agree upon the interconnectedness of living systems. Participants felt that while the population at large might eventually agree upon action to be taken, governments as presently constituted would be unable to respond.

9.1.10 Ethics and culture

The survey group on ethics and culture considered a shift in human values, whereby people agree that the present has an obligation to preserve opportunities for the future, as an important development. This was deemed likely within the 2020–2030 timeframe. This development is related to recognition of the interconnectedness of living systems, which was considered to have about the same probability by survey participants in the politics group. Such shifts in public perception can provide opportunities for improved water management.

The deepening of current inequalities in access to water in poor countries caused by increasing water scarcity was also ranked as important by this group, and deemed likely to occur in the 2020–2030 period.

The acknowledgement of access to safe water as a basic human right by most countries in the world also was considered important. However, despite international recognition, the survey participants considered that respect of the right was likely to occur closer to 2030. Of similar importance was the development of water-related anti-poverty strategies including employment of poor people at water points, in irrigation and in food production. The participants considered that these strategies could be in place in at least 30 countries within the same timeframe. Knowledge sharing was considered likely, with the emergence of collaborative international research and development on the ethical uses of water probable within the 2020–2030 timeframe.

9.2 Responding to the challenges: The past is a poor guide to an uncertain future

Water managers work in an uncertain world. Their first priority is to ensure the security of water supplies. These depend on geophysical parameters that dictate water availability (precipitation, runoff, infiltration), and the determinants of human activities that affect the quality and natural flow of water (e.g. how land use affects storm water runoff), as well as its distribution in space and time. Until recently, the analysis of historical data coupled with stochastic[5] analysis has provided a good basis for examining extremes and sensitivities of water supplies and their robustness, resilience and reliability under past climate variability. For water managers this is the starting point for any realistic analysis, conducted routinely in most managed systems. However, the likelihood of increased variability of future water supply, as a result of climate change, will make analyses based on historical data less reliable.

There is also greater uncertainty on the demand side due to an increase in the number and complexity of choices, which are outgrowing managers' abilities to assimilate and analyse data and make decisions. As an example, there are difficulties in predicting the demand for specific goods and services, including energy, which affect water through production, transport or disposal. These create new uncertainties and associated risks for water managers.

Technological development can address these challenges, but not always. The development of new technologies can help address issues of water production and quality and thus reduce risks, but narrowly targeted technological development that does not take into account impacts on water can worsen existing risks (e.g. the first, current generation of biofuel technologies).

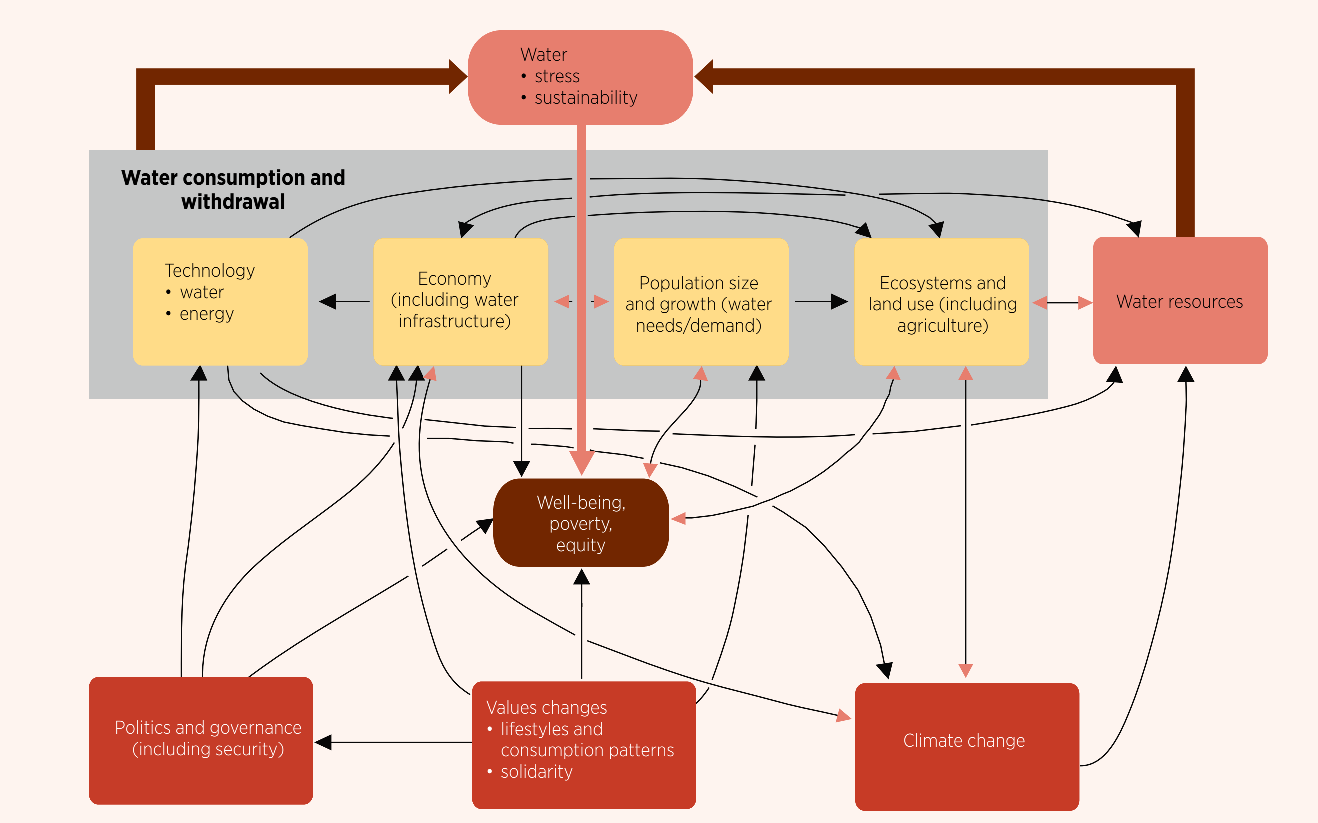
Water managers are aware of the existing and potential vulnerabilities within the systems in which they operate. However, the gathering speed of forces outside their control pose challenges to water management and affect the financial and institutional resources available to meet them. The timescale for agreement on solutions and their implement can stretch to decades, especially for issues with a regional or international dimension. The pace of change reduces the time available for recognizing the problem and agreeing and implementing the right decision at the right time. Decision-makers 'outside the water box' are themselves affected by the uncertainty of how shaping forces will evolve. Water managers can only inform their decisions and manage with the available tools. In this context, it is important to develop relevant information as close as possible to the geographic scale at which they work. Figure 9.1 illustrates the multiplicity of drivers and the complex interactions between them.

9.2.1 Scenario analysis

Scenario analysis is a planning tool for assessing responses to a potentially very different future, depending on how key drivers develop and interact. There are myriad drivers that determine the future situation; therefore, it is rarely possible to consider all of them simultaneously (ten have been discussed

FIGURE 9.1

Key drivers and causal links affecting water stress and sustainability and human well-being



Source: Gallopín (2012, fig. 2, p. 8).

"The timescale for agreement on solutions and their implement can stretch to decades, especially for issues with a regional or international dimension. The pace of change reduces the time available for recognizing the problem and agreeing and implementing the right decision at the right time."

earlier). Consequently, scenario analysis takes a limited number of drivers at a time, and assesses their combined influence on the variables likely to be of particular significance for shaping the future (e.g. population growth and distribution, size of agriculture, and the amount of water used). Sensitivity analysis is undertaken for drivers not included explicitly, to confirm the validity of the scenarios that have been generated. These projections may then be used in the evaluation of policy and planning responses, to maximize benefits and/or minimize losses in achieving the desired state.

World Water Scenarios Project

The major focus of the World Water Scenarios Project[6] is future water availability and its impacts on human well-being, including the health of ecosystems that provide life support. The principal causal links needed to build the logic (or plot) of the scenarios have been tentatively identified. As shown in Figure 9.1, water stress and sustainability (top oval) are functions of the available water resources and their withdrawal and consumption. In turn, both resources and consumption are variables that depend on many factors (only the most relevant are shown). The main drivers are arranged in a sequence from top to bottom showing the proximate drivers (top row of boxes) that directly impinge upon water stress and sustainability, and the ultimate drivers (bottom row of boxes) that exert their effect, mostly through their impacts upon the proximate drivers. Arrows indicate causal influences from and between drivers. In some cases there is reciprocal (feedback) causality between drivers. The next phase of the Scenarios Project will entail developing scenarios and scenario-development tools that can be used by decision-makers.

9.3 Peering into possible futures

Section 9.1 highlighted some of the most important trends likely to affect water and its key drivers over the next forty years, and offered insight on the pressures, uncertainties and risks these create for water resources uses and management. Section 9.2 demonstrated the complexity of the interlinkages between these drivers of change. These will be qualitatively and quantitatively analysed using models as WWAP's World Water Scenarios Project moves ahead.

Even without the benefit of the systematic and analytical approach employed in the World Water Scenarios project, it is useful to consider how certain drivers could interact with each other, and how the trends cumulate in order to examine possible futures for water resources. A set of possible future outcomes are examined here in terms of the positive and negative pressures they are most likely to generate, and the types of uncertainties and risks their evolution may produce, both regionally and globally.

Contemporary crises (food, energy, poverty, health, economy, environmental degradation, climate change) are the result of a combination of various unanticipated pressures or drivers. While reflecting upon these crises and searching for possible solutions, it is also important to try to find ways to avoid future crises. This section provides a superficial exploration of some of the possible outcomes resulting from combinations of the various trends discussed in Section 9.1, and analyses the short and long-term risks involved in each situation. The three scenarios examined below relate to: how we can feed the world population, how the evolution of technology might help, and the role of policies in encouraging a transition to a sustainable economy.

9.3.1 Feeding or not feeding 9 billion people

One possible future aims to analyse the impacts on water of a policy status quo, or to describe what might happen in the absence of any intervention.

The global population is likely to reach 9.1 billion in 2050, if not sooner. While this alone has potentially dire consequences in terms of pressures on natural resources, especially water, a deeper look at demographic trends provides a more concrete portrait of life in 2050. According to the UN Population Division (2010 revision), (UNDESA, 2009) 68% of these 9 billion people will reside in urban settings. At least 32% of the total world population will be under 24 years of age, and on average, people will live longer lives (75.5 years) (UNDESA, 2009). As mentioned in Section 9.1, population growth alone could reduce the percentage of those with improved access to water supply and sanitation by 10%.

Growth in food demand resulting from population growth and changes in nutritional habits, hand in hand with increased urbanization, will likely lead to a multiplied increase in water demand. Other impacts of human settlements will also increase with encroachment on fragile or marginal lands, deforestation and pollution. Most climate change scenarios predict that increasing variability and unpredictability will seriously affect global water availability. As seen in Section 9.1, water availability is expected to decrease in many regions (groundwater recharge, streamflow, rainfall). Yet future global agricultural water consumption alone (including both rainfed and irrigated agriculture) is estimated to increase by about 19% by 2050, and will be even greater in the absence of any technological progress or policy intervention (see Chapter 2). In fact, current trends show that water withdrawals are expected to increase by at least 25% in developing countries (UNEP, 2007).

Natural resources and ecosystems that form the basis of livelihoods are increasingly under pressure from highly intensified and often unsustainable use. For example, 60% of the world's 227 largest rivers are moderately to greatly fragmented by dams or diversions (UNEP, 2007), and the rate of dam construction is increasing worldwide. Deforestation for energy supply and agricultural expansion is leading to soil erosion and declining soil fertility, as well as siltation in many water bodies and reservoirs (reducing the efficiency of dams). As cleared land retains less water, aquifer replenishment decreases and water loss through runoff increases. Paradoxically, land clearing for agriculture does not always lead to significant or proportionate yield increase, particularly in the long term, as soil fertility rapidly declines and cropping becomes more labour-intensive (see e.g. Gibbons, et al, 2009; Juo et al., 1995).

While agriculture continues to use at least 70% of water resources globally, other economic sectors will continue to compete for water resources, and some intensely, without an explicit mechanism for allocation decision-making. In most cases, water will continue to remain an afterthought of economic and sectoral policy. As industry develops, particularly in emerging countries and countries actively pursuing non-agricultural diversification schemes, various sectors present the potential for significant increases in water use. Decisions about allocations between sectors are usually not subject to specific regulations, although some countries explicitly recognize drinking water as a priority.

Pressures on natural resources and the increasing interconnection between national economies mean that the world is likely to continue to grapple with periodical crises, such as the recent food and financial crises, and the impending energy crisis. To add to uncertainty, these complex situations are closely linked, for example, the price of food is closely linked to the price of energy through the costs of transport and fertilizers. Single-market perturbations, caused by political (e.g. conflict in oil-producing countries) or climatic extremes (drought in crop-producing countries) are difficult to predict and have far-reaching and often long-lasting consequences well beyond traditional sectoral boundaries.

Responses to these crises can also have negative impacts on water resources and management, because they inadvertently create a bias towards a given solution focused on a particular water user; more often than not, an intensive water user. For example, attempts to pre-empt an energy crisis through production of biofuels or by tapping into harder to reach, and more water intensive, fossil fuel deposits (oil sands, shale gas) could have negative impacts by diverting land and water from food production, and by creating a more lucrative competing sector. For example, water used for cooling power plants in the United States of America represents 40% of the country's industrial water use. This figure is expected to reach 30% in China in 2030.[7] Increased energy production using current technology, at current levels of efficiency, is therefore likely to exert multiplied pressures on scarce water resources.

In the absence of technological improvements or policy interventions, economic polarities will increase between water-rich and water-poor countries, as well as between sectors or regions within countries. This would mean higher numbers of people with higher needs competing for less water, of lesser quality. Because allocation will inevitably go to the highest paying sector, region or country, this may result in an increasingly significant portion of people not being able to satisfy their basic needs for food, energy, water and sanitation. This would not be mere stagnation, but would likely take the form of a distinctly regressive trend compared to current conditions.

More importantly, this possible outcome represents a high degree of risk and uncertainty. This is because the underlying links between the various drivers are not well understood or are not considered as part of decision-making, and because the long-term impacts on water of key sectoral decisions are being largely ignored. Therefore, this possible future remains highly volatile, with water – despite being an asset for all economic sectors – severely impacted regardless of the outcome or evolution of any single driver. Paradoxically, while this future outcome represents the highest risk for society overall in the long term and the highest degree of uncertainty regarding future water availability and management, it also represents a future in which individuals, governments and the private sector are the least risk-averse in their daily decisions, focusing on short-term benefits rather than long-term potential.

9.3.2 Technological evolution and greater awareness for a greener economy

A second possible future would be determined by the evolution of current technology development trends, highlighted briefly in the previous section. This outcome assumes that technology development is almost exclusively a product of private sector mobilization, responding to existing levels of awareness, market conditions and existing pressures for increasing profit margins in developed countries. The technologies considered here are not necessarily applicable uniquely to water management activities (e.g. filtration technologies), but also to water-using sectors (e.g. agriculture, energy). However, they are all assumed to have the effect of reducing water demand and waste or improving water management.

Among the key anticipated and most likely developments over the next decades is desalination, which has the potential to increase water availability, and would become more efficient and more affordable. Although slow in terms of operationalization, desalination shows potential for providing drinking water in coastal regions within the next 50 years. However, no projections are available for the potential negative impacts of the technology, which at the present moment result in ever-decreasing efficiency because of pollution discharge and over-salinization of the immediate ecosystem. If left unchecked, this technology could have high positive impacts on water supply, but negative impacts on marine and coastal environments from by-products (brine) or excessive intake (WWF, 2007). Desalination uses high levels of energy, raising the issue of yet another trade-off between water supply and energy production. Solar-powered desalination plants, currently being tested in some countries (e.g. Saudi Arabia), might provide a more suitable avenue in sun-rich countries.

A more promising trend, one with fewer trade-offs, but slower private sector mobilization, encompasses various technologies applicable to agricultural water uses and which, combined, could lead to significant water conservation in the most important water-using sector. The further dissemination of water-harvesting technologies, efficient irrigation (e.g. drip irrigation), as well as technologies for the re-use of grey water in peri-urban agriculture could also lead to an increase in water availability for food production. The development of sustainable urban agriculture could also provide resilient avenues for ensuring local food supply. Already, the FAO estimates that 70% of urban households in developing countries participate in agricultural activities (FAO, 2010). The development of bio-fertilization techniques would also increase water use efficiency by promoting higher nutrient absorption and crop growth rates. Increases in on-farm efficiency, brought about by the timely availability of agro-climatic information (to help deal with increasing climate and rainfall variability), early warning systems and mechanization, which is still lagging behind in many countries, could also lead to an overall increase in water use efficiency.

There is a risk that the response of producers to the evolution of these profitable technologies could offset (or even nullify) any gains in water use efficiency; for example, if producers continue to expand agricultural land into marginal or fragile areas (such as wetlands, slopes or forests), resulting in an accelerating rate of deforestation and soil erosion. Nevertheless, the combination of these technological developments would mean an increase in water requirements for agriculture of close to 20–25% (see Chapter 2), rather than an agricultural water requirement increase of 70–90% (as described in Section 9.2.1).

Further technology developments applicable to urban water production and waste handling that are likely to increase due to sheer urban population growth are also expected to contribute to reducing absolute water withdrawals and waste. For example, the development of nanotechnology, cited as one of the most probable anticipated technologies in Section 9.2.1, will help reduce pollution and accelerate the pace of filtration, making water re-use possible and increasingly affordable. Grey-water reuse, along with simple water conservation technologies for urban applications (more efficient toilets, in-house grey water recycling, more efficient showers) would also make water conservation practices for urban dwellers more affordable. The opportunity cost of selecting ecological options would decrease both at the individual and the community scale. This will mean more efficient options for urban planning and an increase in green building design, which will facilitate the efficient integration of new urban migrants.

Similar developments can be expected from anticipated growth in renewable energy technology, and in energy efficiency measures, which are themselves driven by pressures on current energy resources. As water is a key input in almost all energy production (from extraction to cooling), industrial demand for water is expected to increase as population growth is paired with increasing energy demand. The growth in renewable or alternative energy technology will therefore have a beneficial impact on water demand, potentially freeing resources for more efficient uses, perhaps for agriculture. Photovoltaic panels and wind turbines, which have recently expanded in number in many countries, require much less water for production and very little for maintenance. Urban development using cheaper solar energies would therefore reduce water demand.

Rapid uptake of these technologies would be paired with the anticipated evolution of global consciousness regarding human impacts on environment, and in particular, an increased understanding of water scarcity issues (see Section 9.1). Developed country markets, already beginning to show a preference towards 'responsible' products, would continue to encourage technology development, while the availability of affordable green products, practices and options would induce a gradual transformation towards a green economy. This applies to food as well as other consumer goods. It also has the potential to effect a gradual shift in agricultural practices towards organic farming, local or peri-urban agriculture, and overall more sustainable and equitable agriculture, which uses fewer pesticides, maximizes efficiency in its use of inputs including water, and produces higher yields and socio-economic benefits. Recent data shows that markets for organic food and beverages expanded 10–20% on average per year between 2000 and 2007 (Sahota, 2009), resulting in a similar expansion of sustainably managed farmland (UNEP, 2011).

UNEP defines the green economy as 'one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities' (UNEP, 2010, p. 4). A naturally evolving green economy – one brought about without a conscious policy effort through the combined result of technology development and increased awareness – would result in a decreased water footprint in most water-using sectors, in particular agriculture, because of increased conservation, reuse and recycling, and greater efficiency. This would also have positive results on overall poverty reduction and socio-economic development.

In such a future, voluntary labelling of products according to their water efficiency or water use would become more frequent (although not necessarily subject to well-established norms and standards). Fair-trade, green or sustainable labelling would increasingly include a measure of water footprints.

These somewhat spontaneous technology developments (extrapolated from current trends) would produce benefits for water, but might not produce the complete set of expected green-economy benefits for a variety of reasons. First, there may be delays in adoption because of cultural obstacles to technological uptake (for example, resistance to the recycling of sewage water for drinking). Second, there may be structural or policy obstacles to technology transfer and dissemination because of intellectual property barriers, or a lack of investment in research and extension (particularly in the agricultural sector), or a lack of funding, which could lead to regional disparities in access, potentially aggravating current income gaps. Such gaps in access already exist, with small pockets of private sector interests holding the majority of public-interest patents and intellectual property rights. There is a risk that the unregulated development of technology could lead to perpetuated polarities between the 'haves' and 'have-nots'. Finally, inadequate governance and decision-making systems may create market distortions towards inefficient technologies, for example, through inappropriate subsidies or for lack of long-term vision. As a result, this second possible future, although realistically achievable in some targeted places or pockets, will remain suboptimal, highlighting the need for a set of policy responses or measures to bring about more rapid, equitable and sustainable change.

Nevertheless, this possible future represents a marked change in the uncertainty we face, as increased awareness and a marked private-sector interest in emerging opportunities mean that water management is no longer obscured by other short-term gains. In this possible outcome, the impacts on water of various sectoral or interest-based decisions are more readily understood thanks to investments in research and development, and because the possibilities offered by technology are more evident. In this possible future, some segments of the private sector and governments are shouldering a part of the short-term risks by investing in research and development and creating new markets, because the long-term risks are more apparent and the potential benefits are also more clearly understood. However, the long-term risks and uncertainties faced by water users and water-using sectors are still not entirely mitigated. Furthermore, while there is a chance that this spontaneously emerging greener economy has positive impacts on water, there remains uncertainty about continued negative impacts and trade-offs.

9.3.3 Policies that encourage a transition to a sustainable water economy

A third possible future extrapolates on current demographic and technology trends, as well as a set of policy interventions that could be adopted over the next two decades. It presents a picture of a possible future based upon key or important policy decisions regarding financing, poverty reduction, climate change, science, and water governance and overall economic policy being taken.

As highlighted in Section 9.2.2, a legally binding international agreement to combat climate change could be in place by 2040, along with significant financing for awareness-raising and adaptation in low-income countries. Because most climate change impacts are felt through water, this would have positive repercussions on the overall levels of financing for water. This could mean higher levels of investment in water infrastructure, leading to reductions in waste and increases in sustainable mobilization, as well as increased sanitation network coverage. The adoption of a concerted effort to curb greenhouse gas emissions would send a clear signal to the private sector concerning the further development of alternative and renewable energies, confirming a trend explored in the above technology-driven future. Hence, technology development for water extraction and distribution, and reductions in industrial water use (especially for energy), are also expected from the adoption of an optimal climate change regime.

Stronger concerted efforts to reduce poverty would also yield significant benefits for water and sanitation, through an increase in funding for water-related initiatives. As water is often a constraining factor on agricultural productivity and other forms of economic development, investment in water management and conservation, as well as sanitation, is expected to deliver multiplied poverty-reduction benefits. Moreover, debt forgiveness – also among the potentially expected international policy decisions – could free substantial levels of funding for water infrastructure and development.

At the national level, another key policy might be achieved by establishing fair prices for water. This would be contingent on the development of solid property regimes, documented land tenure arrangements, and clearly established water rights and allocation systems. However, if coupled with a growing sense of awareness among local populations and a generally higher level of understanding of water issues, the more likely outcome would be the integration of water issues into development planning, particularly urban planning. Adequate revenues from water management would also allow for the regular maintenance of water infrastructure and reduce contamination and leakages.

"Debt forgiveness – also among the potentially expected international policy decisions – could free substantial levels of funding for water infrastructure and development."

Other policy changes would include the removal of unsustainable subsidies in agriculture and overall agricultural trade liberalization. Subsidies that encourage inefficient uses of land, water and fertilizers, and create market distortions towards higher water users, would be gradually replaced by flexible, index-based insurance schemes that allow producers to make short-term cropping decisions based on climate variability and extremes, while encouraging intra-seasonal innovation and technological upgrading of cultivation practices. This, coupled with increased spending on agricultural technology, extension and research (as an engine of economic recovery), would lead to significant water efficiency gains in the agriculture sector alone. Models developed recently for the UNEP Green Economy initiative show that trade liberalization tends to reduce water use in water-scarce regions and increase water use in water-abundant regions, meaning that water would be allocated to its most effective use at the global level (Calzadilla et al., 2010). There is, however, a risk that without transparent and equity-based local allocation mechanisms, further liberalization could still create barriers or difficulties of water access for smaller producers.

Another policy shift might be inspired by the recognition that healthy environments provide key services, in particular, water. Hence, governments at the local, subregional and national levels could begin investing in the restoration and rehabilitation of key ecosystem functions. As a result, productivity would increase without jeopardizing key environmental services. This would be greatly facilitated by current technology development trends and increases in awareness, particularly in developed countries. It would also be supported by the increased understanding that healthy ecosystems can help adapt to the effects of climate change while maintaining local livelihoods. As seen in recent studies, water-related services provided by healthy ecosystems, such as mangroves, forests and wetlands, compare favourably with those provided by man-made structures (such as treatment plants), which usually come with much higher costs (see TEEB, 2010; World Bank, 2010), shorter life-spans, and are potentially less resistant to anticipated climate changes.

Increased awareness among the global and national population, coupled with increased access to information and increased inclusiveness and participation of stakeholders everywhere, could also lead to shifts in water governance within and between countries. With recognition of the fact that water is best managed at local levels, water-basin institutions and decentralized authorities would be given increased power and resources to effectively manage water within countries. This would promote local and climate-responsive allocation of water among users, facilitated by well-regulated pricing and, potentially, innovative water rights trading mechanisms. It would ensure that basic water needs are met, as well as needs for environmental purposes, while promoting the most efficient uses of water. For shared basins, transparent processes for allocation and distribution could emerge, provided other market distortions are removed and trade is further liberalized as mentioned above.

A deeper evolution in values may be required, including a decline in consumerism and conscious efforts to reduce energy consumption at the individual and local level, specifically in developed countries. This may also require a softening of aspirations to food sovereignty (i.e. production of all food locally regardless of impacts on water) to allow for the emergence of fairer international trading systems. While water has been recognized as a human right, mentalities may need to evolve to allow for equitable water prices to emerge.

Communities and countries would be better prepared for uncertainties and more adept at managing long-term risks to water with increased information, participation and dialogue among water users, and a longer-term view towards (and acceptance of) holistic approaches. This outcome represents the product of concerted thinking and action based on potential risks and trade-offs. Uncertainties would be reduced due to the increase in information and knowledge, and the adoption of clear policies would provide signals to markets, further reducing risks. In this future, each segment of society shoulders a part of the short-term risks involved in changing policies or practices and developing new products and markets, allowing for a reduction of the global long-term risks.

9.4 Water futures for better decision-making

These exercises in future thinking provide a cursory view of potential futures and an illustration of the interconnections between the various drivers. They illustrate the possible impacts of a set of strong policies and choices that may appear difficult (or risky) today, but are most likely to yield rapid economic and livelihood benefits at all levels and reduce long-term risks and uncertainties.

However, more concrete, rational and scientific modelling of water futures is necessary to better calibrate and explore these possible futures, including the development of regional and global water scenarios. Lack of knowledge is one of the key limitations to adopting some of the measures noted above. Targeted and relevant knowledge is necessary to make informed 'no-regrets' policy decisions, whether at the international, national or local level. Knowledge reduces uncertainties and makes risks more manageable at the individual, community and international level.

This includes science-based and consensus-based measures of the water footprint of various products; measures of water-use efficiency for energy supply technology, basic appliances and crops; downscaled climate and hydrological models that would allow for basin-based allocation decision-making; and economics-based modelling that would provide financial information on the rates of return of various policy measures and investments, including infrastructure, ecosystem rehabilitation or diversification – as well as information on the long-term costs of inaction. The comprehensive and rigorous water scenarios being developed as part of WWAP's World Water Scenarios Project, should provide a stronger indication of policy pathways towards (or avoidance of) determined water futures. The development of water scenarios appears ever more necessary in the face of the risks and uncertainties involved in continuing with the business-as-usual modes of water management.

Notes

1 A significant number of scenarios related to water at the global and other geographic scales were identified and examined to determine drivers that should be reviewed in the WWAP scenarios project. Through this review, ten drivers were identified for in-depth research by graduate-level researchers, to examine possible future developments in each of the domains while also seeking to identify inter–linkages with some of the other selected drivers. See the two WWAP 'Global Water Futures 2050' publications *Five Stylized Scenarios* (G. Gallopín) and *The Dynamics of Global Water Futures: Driving Forces 2011–2050* (C. E. Cosgrove and W. J. Cosgrove).

2 The occurrence of droughts is determined largely by changes in sea surface temperatures, especially in the tropics, through changes in atmospheric circulation and precipitation. Over the past three decades, droughts have become more widespread, intense and persistent due to decreased precipitation over land and rising temperatures, resulting in enhanced evapotranspiration and drying.

3 Based on the United Nations Population Division's quinquennial estimates and projections. World Population Prospects, 2006 revision, and the UN Common Database code 13600.

4 For more information see the Fund for Peace website http://www.fundforpeace.org

5 Stochastic analysis is defined as having a probability distribution, usually with finite variance.

6 A project of the World Water Assessment Programme (WWAP) partially funded via UN-Water.

7 National Research Council (2010) and 2030 Water Resources Group (2009) as cited in UNEP (2011) (GER 4).

References

Bates, B. C., Kundzewicz, Z. W., Wu, S. and Palutikof, J. P. (eds). 2008. *Climate Change and Water.* Technical Paper of the Intergovernmental Panel on Climate Change (IPCC). Geneva, IPCC Secretariat.

Calzadilla, A., Rehdanz, K. and Tol, R. J. S. 2010. *The Impacts of Climate Change and Trade Liberalisation on Global Agriculture.* Working Papers. Hamburg, Germany, Sustainability and Global Change research unit, Hamburg University.

Cosgrove, C. and Cosgrove, W. 2011. *Using Water Wisely: Global Drivers of Change.* Paris, UNESCO.

Cosgrove, W. J. and Rijsberman, F. R. 2000. *World Water Vision: Making Water Everybody's Business.* London, Earthscan.

FAO (Food and Agriculture Organization of the United Nations). 2010. *Fighting Poverty and Hunger – What Role for Urban Agriculture?* Policy Brief No. 10. Rome, FAO.

Fund for Peace. 2011. *The Fund for Peace* website. Washington DC, Fund for Peace. http://www.fundforpeace.org. (Accessed 30 May 2010.)

Gallopín, G. C. 2012. *Five Stylized Scenarios.* Perugia, Italy, UNESCO-WWAP.

Gibbons, P., Briggs, S. V., Ayers, D., Seddon, J., Doyle, S., Cosier, P., McElhinny, C., Pelly, V. and Roberts, K. 2009. An operational method to assess impacts of land clearing on terrestrial biodiversity. *Ecological Indicators,* Vol. 9, No. 1, pp. 26–40. New York, Elsevier.

Juo, A. S. R., Franzluebbers K., Dabiri A. and Ikhile B. 1995. Changes in soil properties during long-term fallow and continuous cultivation after forest clearing in Nigeria. *Agriculture, Ecosystems & Environment,* Vol. 56, No. 1, pp. 9–18.

Nakicenovic, N. (ed.) 2000. IPCC *Special Report on Emissions Scenarios.* Prepared by the Intergovernmental Panel on Climate Change (IPCC) Working Group III for COP 6. Geneva, United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO).

Sahota, A. 2009. The global market for organic food and drink. H. Willer and L. Kilcher (eds) *The World of Organic Agriculture: Statistics and Emerging Trends 2009.* FIBL-IFOAM Report. Bonn/Frick/Geneva, International Federation of Organic Agriculture Movements (IFOAM)/ Research Institute of Organic Agriculture (FiBL)/ International Trade Centre (ITC). http://orgprints.org/18380/16/willer-kilcher-2009.pdf

TEEB (The Economics of Ecosystems and Biodiversity). 2010. *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.* Geneva, United Nations Environment Programme (UNEP).

UNDESA (United Nations Department of Economic and Social Affairs). 2009. *World Population Prospects, The 2008 Revision – Executive Summary.* New York, UNDESA.

UNEP (United Nations Environment Programme). 2007. *Global Environmental Outlook 4 – Environment for Development.* Nairobi, UNEP.

––––. 2010. *Driving a Green Economy Through Public Finance and Fiscal Policy Reform.* Nairobi, UNEP. http://www.unep.org/greeneconomy/Portals/88/documents/ger/GER_Working_Paper_Public_Finance.pdf

––––. 2011. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication.* Nairobi, UNEP. http://www.unep.org/GreenEconomy/Portals/93/documents/Full_GER_screen.pdf

World Bank. 2010. *The Economics of Adaptation to Climate Change.* Washington DC, The World Bank.

WWF (World Wide Fund for Nature). 2007. *Making Water – Desalination: Option or Distraction for a Thirsty World?* Gland, Switzerland, WWF.

CHAPTER 10

Unvalued water leads to an uncertain future

Author James Winpenny

The policies that shape water governance are commonly formulated by politicians and officials in planning, economic, finance and water-using departments. As such, national economic and financial considerations play a highly influential role. The case for investment in water and for reforming its development and management is also often framed by others in social, ethical, equity or public health terms. As a consequence, the real importance of reform is not always apparent in public decisions. In the face of rapid change and uncertainty there is a risk that this situation will continue or worsen, creating even greater challenges. It is vital therefore that the case for reform be adequately stated in economic terms. This chapter sets out the elements of such an economic case, starting with the overall benefits of water to an economy, and proceeding to consider the value of water in the various parts of its cycle. These benefits and values can be used to inform policies for the allocation and use of water in situations of growing resource pressures, uncertainties and associated risks.

10.1 The political economy of investing in water: Stating the benefits

Investing in water has various economic benefits. In particular, it promotes the growth of national income by providing:

- Security against fluctuations in the availability of water (mitigating both floods and droughts) and promotion of long-term climate resilience.
- A growth catalyst by opening up new types of economic activity, which were not previously feasible.
- Ongoing benefits in terms of added value and welfare for users throughout the hydrological cycle. These users include economically productive sectors such as agriculture, industry, hydropower, navigation, recreation and tourism, and households. Water also constitutes a vital input to ecosystems and all aquatic habitats, which in turn provide essential life support in addition to services with an economic value.

The following three sections examine these benefits in turn.

10.1.1 A buffer against climatic fluctuations and a key to climate resilience

There is no universally accepted definition of water security; the term can mean different things in different contexts. In general, it reflects a country's ability to function productively in the face of water vulnerability. This has been expressed (e.g. Grey and Sadoff, 2008) as the need for all societies to have a *minimum platform* of investment in water institutions and infrastructure as a basis for water security. Below this minimum, societies are too vulnerable to water shocks and unreliable water supply for production or human livelihoods: 'social fabric is significantly affected and economic growth cannot be reliably and predictably managed' (Grey and Sadoff, 2008,, p. 7). Once the minimum platform has been put in place, basic needs are satisfied and further water development can stimulate economic growth.

Many countries where this concept is most relevant are regularly devastated by climatic extremes, fail to meet the basic household needs of their populations, and cannot offer reliable water services to their farmers and industries. In such economies investment in agriculture is discouraged, while an unreliable water supply is also a deterrent to the development of industry and services (AICD, 2010). A greater ability to counteract climatic variability can avoid the worst costs of droughts and flooding. In Kenya losses from flooding from El Niño in 1997-98 and drought from La Niña in 1998-2000 ranged from 10-16% of GDP during those years. Growth of GDP in Mozambique was reduced by 1% annually due to water shocks. In Zambia hydrological variability is estimated to lower agricultural growth by 1% each year. In Tanzania the impact of the 2006 drought on agriculture caused losses equivalent to 1% of GDP ([McKinsey, 2009)]. Reducing the damaging impact of this hydrological variability would have major benefits for the macroeconomy (AICD, 2010).

The strong likelihood of climate change is an additional justification for implementing projects to strengthen water security. However, many such projects are justifiable even without this scenario. *No regret and low regret* projects generate net social and/or economic benefit irrespective of the impacts and consequences of climate change. Many of these projects would enable an economy to better cope with existing climatic variability, irrespective of future changes.

10.1.2 Water infrastructure as a catalyst for economic growth

The harnessing and development of water resources has been a fundamental driver of economic growth in many countries and periods throughout history. For example, it constituted the major factor in the development of the western United States of America throughout much of the twentieth century, and galvanized the recovery of the Tennessee Valley region from the Great Depression of the 1930s (Delli Priscoli, 2008). The role of water resources development in economic growth in Arizona (USA), Korea and Turkey is covered extensively in Mays (2006).

The construction of large dams has become controversial. It is therefore important to fully assess the alternatives and to be aware of, and properly manage, their social and environmental impacts (World Commission on Dams, 2009). Nevertheless, investment in large dams in certain regions (e.g. the Aswan, Kariba and Volta dams in Africa) has provided a major stimulus for the development and diversification of the host economies (Granit and Lindstrom, 2009). Subject to the above-mentioned qualifications, climate change reinforces the existing case for providing greater water storage in Africa and elsewhere.

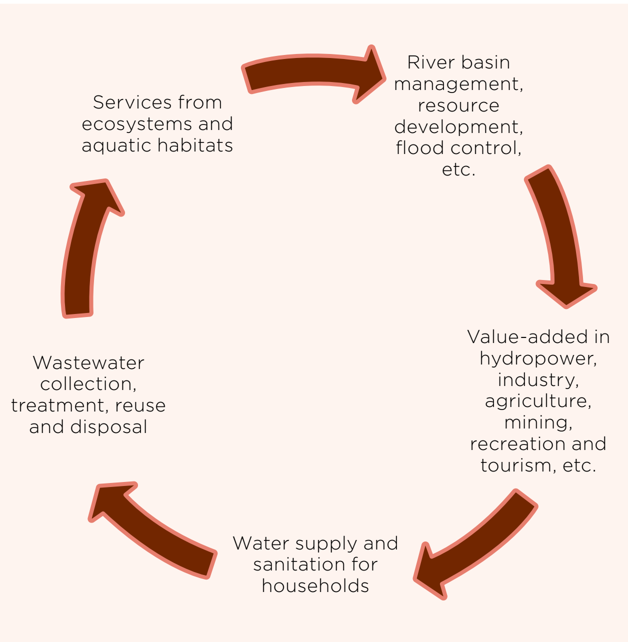
10.1.3 The whole-cycle benefits of water

Much of the water resulting from rainfall and other precipitation is stored in lakes, aquifers and so on for multiple uses, after which it is returned to rivers, lakes or groundwater for further use.[1] Although water is often misleadingly referred to as a sector, it is actually a ubiquitous medium, and one that creates benefits at each part of its hydrological cycle (Figure 10.1). The many facets of water can also be viewed as a *value chain* (OECD, 2010).

The development and management of watersheds and catchments spans a range of activities, both 'hard' and 'soft'. The spectrum varies from major multi-purpose storage schemes to activities entailed in the protection and enhancement of watershed and river basin functions including afforestation, catchment management, land use controls, and so on. Many of these activities are carried out by land users themselves, as in the case of farmers responding to incentives and sanctions. These activities create value for downstream communities through savings in costs that would otherwise be incurred. In New York State, a programme for watershed protection that encourages farmers in the upper catchment area to convert to more environmentally friendly cultivation practices is expected to lead to substantial savings in downstream water treatment for the population of New York City (Salzman, 2005; OECD, 2010). Data from other American cities (Portland Oregon, Portland Maine and Seattle) confirm the significant financial savings from watershed protection, compared with the cost of building new water

FIGURE 10.1

Benefits from the water cycle



treatment and filtration systems (Emerton and Bos, 2004). Similar experiences exist in Latin America, as for example in Brazil, Costa Rica, Ecuador and Salvador (Dourojeanni and Jouravlev, 1999; Jouravlev, 2003).

Upstream investment and management can benefit downstream users in other ways, directly and indirectly. Greater regularity of flows of good quality water can save costs of storage, development and treatment for urban waterworks, industrial abstractors, farmers and other water users. The maintenance of minimum river flows creates assimilative capacity for wastewater releases (which would otherwise need pre-treatment) and provides 'flushing' for rivers with a heavy sediment load. In each of these cases, any impairment of the natural river functions due to inadequate management would require costly human interventions to deal with the problems caused.

Water is increasingly a critical factor in decisions regarding the location of economic activities such as industry, mining, power and tourism. Companies working or contemplating investment in water-stressed regions are becoming aware of their 'water footprint' and its impact on local communities, which could pose operational and reputational risks to their business. A growing number of countries will also face increasing difficulties in providing water to their growing water-intensive cities, farms and industries. Investment in measures to bring supply and demand into better alignment can safeguard future development in such cases.

In a study of the water supply-demand balance in four rapidly growing countries and regions – China, India, the state of Sao Paulo in Brazil and South Africa – current trajectories and unchanged policies produce growth projections to 2030 incompatible with water endowments. Achieving the required growth targets will necessitate action to close the potential supply-demand gap for water, combining investments in supply enhancement and measures of demand management (McKinsey, 2009).

The most visible and best-studied aspect of the water cycle concerns household services – the benefits to individual people and their families from receiving clean, safe water and associated sanitation in a reliable fashion or close to where they live. People receiving such services are at less risk of contracting water-borne disease, spend less time fetching water and less money buying it, and have more time and energy available

> "The principal benefits of wastewater treatment are avoidance of the costs of pollution and of the use of contaminated water by downstream users, such as other municipalities, industries, farmers and the tourism industry."

for personal washing, cooking and domestic cleaning. Likewise, improved household sanitation provides numerous benefits for public health, as well as less time spent seeking privacy, more dignity and less embarrassment, greater opportunities for female education, and greater pride and communal and personal prestige.[2] Lentini (2010) and Oblitas de Ruiz (2010) provide an exhaustive overview of the many and diverse benefits of water services in a typical developing country setting, and Lentini (2010) also presents a methodology for their monetary estimation.

These potential benefits cannot be fully captured in economic terms, although evidence is becoming available that is suggestive of the size of benefits and their returns on the investment. Empirical studies carried out at the World Health Organization (WHO) and elsewhere show that investments in a range of water supply and sanitation interventions can have high economic benefit-cost ratios. The benefits are typically savings in time spent in household duties, including fetching water and, to a lesser extent, savings in the various costs incurred in illness and medical treatment (Hutton and Haller, 2004).

The following interventions were modelled in the above-mentioned study:

1. The drinking water part of the target to 'halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation', with priority given to those already with improved sanitation (UN, 2010, p. 58, Target 7c)
2. The above target for both water and sanitation
3. Access for all to improved water and sanitation
4. Universal disinfection of water at point of use on top of intervention (3)
5. Universal access to regulated, piped water and sewage connections into homes

For each of the 17 WHO regions and for each of the five interventions models, benefit-cost ratios were positive, some spectacularly so[3] (Hutton and Haller, 2004, pp. 35 and 64).

The economic benefits of sanitation include time saved from queuing for public toilets or seeking out secluded spots in the open; increased school attendance, especially for adolescent girls; and gains in national productivity from the greater ease of employing women where proper sanitation facilities are provided. Local standards of sanitation also have an effect on tourist visits to areas concerned (OECD, 2010, p. 33).

In Indonesia, World Bank research estimates that the country lost US$6.3 billion (2.3% of GDP) in 2006 from poor sanitation and hygiene. The result was increased health costs, economic losses, and offsetting costs in other sectors (World Bank, 2008*b*). Corresponding losses in the Philippines as part of the same overall study amounted to US$41.4 billion or 1.5% of GDP (World Bank, 2008*a*).

Investment in safe wastewater collection and treatment, including industrial effluents, can also remove a potential brake on economic activity. It has been estimated that water pollution in South Africa costs the country 1% of its annual national income (Pegram and Schreiner, 2010). The principal benefits of wastewater treatment are avoidance of the costs of pollution and of the use of contaminated water by downstream users, such as other municipalities, industries, farmers and the tourism industry. In serious cases, the pollution of water bodies has caused industries to be closed down and relocated at great cost, or impede access of agricultural and fishery products to international markets.

Water continues to provide benefits after its use by households, industries and others. Growing water stress in many regions is leading to a greater appreciation of the economic value of wastewater. The recycling of municipal wastewater for agriculture, urban landscaping, industrial cooling, groundwater recharge, restoring environmental flows and wetlands, and for further urban consumption is increasing rapidly in water-scarce countries.

An important part of water infrastructure consists of natural systems such as forests, catchments and wetlands that store water, regulate its flow and help to preserve its quality. If these natural systems are destroyed or compromised, their functions have to be replaced by man-made facilities, often at high cost. In one example, the flood attenuation functions of the Muthurajawela Marsh, a peat bog in Sri Lanka, were valued at US$5 million annually, in relation to the mitigative or avertive spending that would be needed if it were lost. The same is true for the Nakivubo Swamp in Uganda, which runs through the capital city Kampala and has a key role in assuring urban water quality. A large amount of untreated household sewage and the effluent of the city's sewage works enters the swamp prior to passing into Lake Victoria, close to the intake of the water works supplying the city with drinking water. The swamp provides natural filtration and purification of the wastewater: the infrastructure required to provide a similar level of wastewater treatment would cost up to US$2 million per year (Emerton and Bos, 2004).

Contrary to the common view that water and irrigation are uneconomic investments, a comparison of the (weighted) average economic rates of return for both water supply and irrigation projects in sub-Saharan Africa shows that they compare favourably in relation to other types of infrastructure (Table 10.1).

10.2 Valuing water

10.2.1 Water's manifold value

The benefits of the water services mentioned above are based on the economic value of water in its various states and uses. Valuing the multiple socio-economic benefits of water is essential to improving the decisions of governments, international organizations, the donor community, civil society and other stakeholders. Conversely, a failure to fully value all the benefits of water in its different uses is a root cause of the political neglect of water and its mismanagement. It leads to insufficient appreciation of the importance of water; suboptimal levels of investment in water infrastructure; and the low priority accorded to water policy in country development programmes, poverty reduction strategies and other policies. Finally, it plays a significant part in the failure to meet international socio-economic objectives.

Valuing water should facilitate water resources and services to be added or compared, or allocated to maximize social welfare. However, not all the benefits of water can be quantified or expressed in monetary terms. There are many limitations to the methods developed to derive the economic value of water in its different uses: some are controversial, have high data requirements, are complex, or require technical and economic skills. Valuation is an eclectic discipline, with different techniques for different uses and policy purposes. But although the production of a comprehensive system of economic values for water is an over-ambitious task, some useful results have been produced in specific local or regional contexts from multi-stakeholder processes involving actors with different subjective valuations.

Such political and technical dialogues can lead to broad agreement, which is useful for setting policies. However, different groups of people value water in different ways and even the same group's perceptions can alter as conditions change. Moss et al. (2003, p. 46) argue that 'the complexity of the interfaces between many different stakeholders and the tendency for water to raise strong emotions frequently leads "value differences" to become "value divides".' These can lead to polarization that blocks dialogue and

TABLE 10.1

Economic rates of return for infrastructure projects in sub-Saharan Africa (%)

Railway rehabilitation	Irrigation	Road rehabilitation	Road upgrades	Road maintenance	Power generation	Water supply
5.1	22.2	24.2	17.0	138.8	18.9	23.3

Source: AICD (2010, p. 71).

prevents reasonable governance solutions. Improved understanding of the value differences can help identify commonalities and interdependencies that may be useful for negotiated agreements.

According to the OECD (2010), the lack of a coherent analysis of investment benefits across the entire value chain of water and sanitation is due to the fragmented markets in which water services are delivered. Although ministries are responsible for setting overall policy direction, investments are made by utilities and agencies operating at a decentralized level, often in an uncoordinated manner. As a result, the benefits (and costs) of a wider range of investments across the full value chain of water management and services do not receive adequate assessment.

10.2.2 Economic values of water in different uses

The Dublin Statement on Water and Sustainable Development (1992) states that 'water has an economic value in all its competing uses and should be recognised as an economic good'. A distinction needs to be made between the value, cost and price of water, which are often very different from each other. The economic value of water is particularly apparent in situations of water scarcity. Water has different economic values in its different uses. It has an economic cost of supply, which also varies in different situations and for different purposes. Water provided to a particular user, in a specific place, at a certain time has an economic benefit, but also entails an economic cost. The relationship between the specific benefit and the specific cost is the basis of the economic justification for supplying that user. Finally, the price of water is a financial or fiscal transaction between the provider and the user, which is often closely controlled by public authorities, and often bears little relation to either its value in specific uses, or its cost of supply.

Allocating water purely on the basis of such economic principles is complicated and difficult to apply in practice (Turner et al., 2004; Winpenny, 1997). However, the basic concept of comparing the costs and benefits of supplying water in specific locations and to specific categories of users is fundamental to water policy, especially in situations of growing stress. This requires an estimation, however approximate, of the value of the water in its various states and uses.

The methods of valuing water are eclectic and depend on the sector concerned, the type of use and the information available (Winpenny et al., 2010). Household consumption is commonly valued using evidence of willingness to pay (WTP) from direct surveys that make use of structured questionnaires or 'choice experiments' survey techniques. This 'stated value' approach can be supplemented and cross-checked by evidence of revealed preference, such as inferring users' preferences from their changes in consumption following a tariff change, or by estimating their actual expenditure.

Irrigation water use can be valued in either of two different ways. The marginal productivity of water (the extra value of output that can be obtained from additional applications of water) can be estimated from changes in yields during crop-water trials. Alternatively, the more common approach (the 'netback' method) is to derive the value of water from farm budget data as the residual after all other costs have been allowed for. This latter method makes the crude assumption that the residual, or unexplained, farm surplus is due entirely to water, rather than to other factors.

Industrial water valuation poses a greater problem. For many industrial (and commercial) enterprises, water constitutes a small part of their total costs. It would therefore be misleading to use the residual method, as for irrigation, and attribute the whole residual surplus to water. Much industrial bulk water is self-supplied from wells and rivers. Many firms recycle water by treating and reusing waste flows. One valuation approach regards the cost of recycling as the upper limit on industrial WTP, because firms would rationally recycle rather than buy in above this level.

The above uses all involve the abstraction of water. However, water also has in-stream values for waste assimilation and dilution, flushing sediment, the functioning of ecological systems, navigation, and various kinds of recreation (water sports, sight-seeing, fishing, rambling, etc.). Various valuation options can be applied to these uses. Often, these natural functions of water (assimilation, dilution, flushing) can be compared with the extra cost of alternatives (dredging, treatment). The value of water for navigation can be imputed from its cost advantage over the next cheapest transport mode (e.g. railways). The value of water for recreation and ecological purposes (the maintenance of low flow regimes and wetlands) is generally estimated by WTP or travel cost[4] surveys.

It is increasingly common to use the *benefit transfer approach* to derive empirical values for these environmental effects. As the term suggests, evidence is transferred from situations where it is available to locations and projects which seem to be broadly comparable.[5]

Hydropower water usage is normally valued according to the cost advantage of hydro over thermal power and other alternative ways of generating electricity. In this, as in other cases, it is important to compare like with like, and to be clear about the basis of the estimate.[6]

There have been a number of comprehensive studies of the economic value of water in different uses, and a number of more selective exercises. The earliest studies use data from the USA, but more recent studies from other regions broadly endorse their results. Table 10.2 indicates the results of a recent comparative US study.

The evidence presented in Turner et al. (2004, p. 91) shows that the value of water for *irrigated agriculture* of many low-value crops (typically food grains and animal fodder) is very low. By the same token, water values can be high for high-value crops (e.g. fruit, vegetables, flowers) where the water is reliable. The same is true for supplementary irrigation taken as insurance against drought. These results are supported by the actual prices paid for water where water markets exist. In short, the value attached to irrigation water depends heavily on how reliable it is and on the type of crop being produced. Values tend to be higher for privately owned groundwater than for publicly supplied surface water schemes.

"Household water used for truly essential needs such as drinking, cooking and basic hygiene comprises only a minor part of typical daily use; the rest is used for 'lifestyle' or productive purposes."

Household values are relatively high, but this is not a homogeneous category. Household water used for truly essential needs such as drinking, cooking and basic hygiene comprises only a minor part of typical daily use; the rest is used for 'lifestyle' or productive purposes. In affluent regions with a warm climate a high proportion of water is used for outdoor purposes such as watering gardens and lawns, washing cars and filling swimming pools. Households tend to place a higher value on indoor than outdoor uses, though this would not apply where water is used for productive purposes. In some societies, much of the water available to households is used for growing crops and feeding livestock (in other words, it is supplied for *multiple use* purposes). In practice, the valuation of water for

TABLE 10.2

Economic value of water use in the USA: US$ in 1995 prices per acre-foot of water

	Average	Median	Minimum	Maximum	No. of observations
In situ uses					
Waste disposal	3	1	0	12	23
Recreational and habitat	48	5	0	2 642	211
Navigation	146	10	0	483	7
Hydropower	25	21	1	113	57

Note: Acre-foot is the amount of water entailed in covering one acre to a depth of one foot. In metric terms, an acre-foot corresponds to 0.1233 m^3 per ha.
Source: Turner et al. (2004, table 9, p. 92).

household use is commonly taken to be equivalent to the average tariff, which usually underestimates the economic cost of supply and ignores the *consumer surplus*[7] involved.

The value of water with regard to its *environmental uses* is not adequately represented in the studies described above, which relate mainly to *use values*, in particular recreation. In fact, recreational values show great variation, depending on the visitation rate, the location of the site, the quality of water and the type of recreation (with fishing and shooting licences attracting high fees in some countries). Failure to account for these benefits in water valuation can result in inefficient water allocation decisions. Valuations of the non-use environmental benefits of water employ a range of techniques and produce a wide spectrum of results, although typical values tend to fall in between agricultural and municipal/household levels (Turner et al., 2004, p. 92).

10.3 Using benefits and values to inform water policies

A sense of the economic value of water in its different states and uses is a necessary part of water management. This is true in routine management of river basins and the operation of multi-purpose storage schemes, where decisions on allocations have to be made in real-time, day-to-day situations. It also applies to seasonal drought responses and even more so to strategic decisions on adaptation to growing water stress and supply-demand imbalances.

In a functioning water market, economic values will establish themselves through trading prices. However, water markets are characterized by various degrees of imperfect competition, externalities, uncertainty, asymmetric information and distributional impacts. These characteristics affect the appropriateness of market prices for use as measures of value (Saliba et al., 1987). As a result, most observed market prices deviate from an ideal measure of willingness to pay, and may serve only as a rough indicator of the marginal value of additions to regional water supply if the additional volume of water made available is small relative to the region's total supply.

A more complete analysis of differential water values and market failures is desirable in decisions to allow for and regulate water trading, for example, when it is in the public interest to allow trading between rights holders. Trading water rights among farmers during Australia's recent eight-year drought greatly mitigated its impact on agriculture in the Murray–Darling Basin. Water transfers from low to higher value purposes meant that a 70% fall in the availability of water only led to a 30% fall in the value of production (Sadoff and Muller, 2009).

Using water values to inform management and allocation policies does not imply that markets should have the last word in such decisions. As is the case with other sectors, the market can be a good servant but a poor master. Public authorities need to intervene to establish regulations designed to prevent transfer of negative externalities, ensure adequate supplies of water and sanitation services to satisfy basic needs, and safeguard public health.

The value of adequate water supplies to the natural environment is another aspect that requires active public intervention. In the Murray–Darling Basin growing aridity is increasing water losses from evaporation, which threatens water-dependent ecosystems, whose needs have to be weighed alongside those of other uses (Young and McColl, 2009).

10.4 Allocating water under conditions of risk and uncertainty

Recognition and acceptance of the economic value of water will add an economic dimension to the social, ethical, public health and equity dimensions of allocating water. The latter dimensions by themselves have failed to generate the required investments in water to meet socio-economic development objectives.

The allocation of scarce water to competing uses lies at the heart of water management. In many parts of the world, increasing pressures on water resources are leading to a shortage of water to satisfy all needs. In general, four interrelated processes drive water stresses: population growth; economic growth; increased demand for food, feed and energy (of which biofuel is one source); and increased climate variability. Choices must be made about how to share, allocate and reallocate the increasingly scarce water – within sectors, from one user group to another and between sectors. Such dilemmas invoke debates about the principles that should guide water allocations, and how access and equity, economic efficiency, sustainability and existing customary norms and values can be reconciled in specific contexts.

Typically, water allocations are the outcome of dialogue between interested stakeholders. Such parties need to build convergence in their 'value perspectives' (Figures 10.2 and 10.3).

Water allocation embraces practices that vary greatly in scale and duration. They include: the grant of water rights or permits to large irrigation schemes expected to last for decades or even indefinitely, while effective and beneficial use continues; hourly allocation schedules between irrigators; short-term reservoir releases to cover peak demands in the electricity grid; and schedules for rationing water between industries, essential services, power generation, farmers and households in the event of drought.

There are four main aspects of a water allocation system:

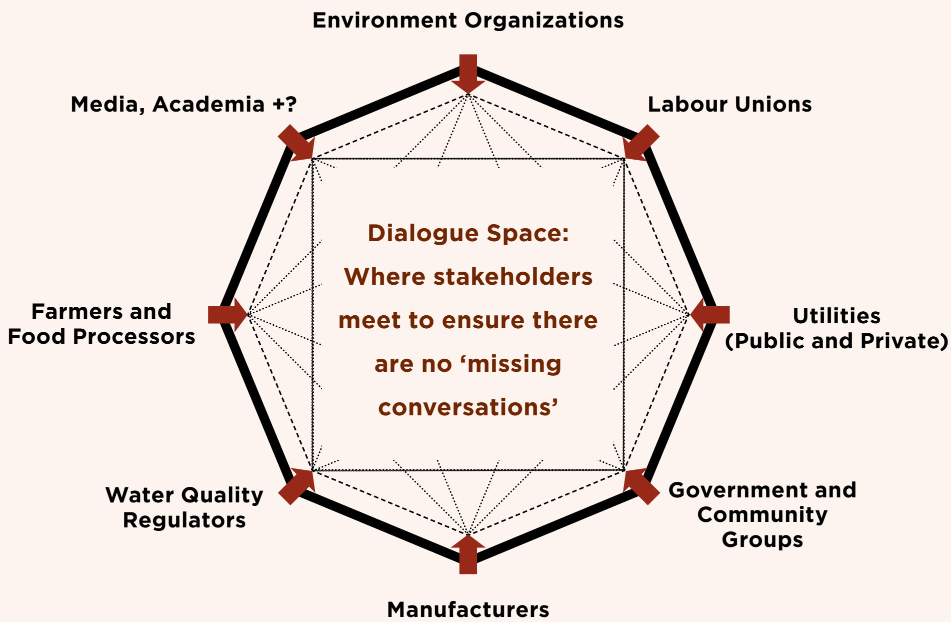
- *Water entitlements* (formal or informal) confer on the holder the right to withdraw water and apply it in a generally recognized beneficial use (Le Quesne et al., 2007). A person's entitlement to withdraw water must be considered legitimate by others.
- *Water allocation* is a process whereby the available water is shared among, and distributed to, legitimate claimants (Le Quesne et al., 2007).
- *Water service delivery (or control)* is the physical act of supplying water to those who are entitled to it in such a manner that they can effectively use it.
- *Water use* is any deliberate application of water to a specified purpose (Perry, 2007).

Water entitlements, allocation, service delivery and use are dynamically linked and constrained by the amount of water that is available at specific times. The use of water creates expectations of similar use in the future. If it is continued over time an entitlement emerges, which may be difficult to ignore or claim back; yet the amount of water available is prone to natural and man-made fluctuations and changes.

The increasingly variable hydrological cycle makes the availability of the resource more uncertain both in time and geographically. Demographic, technological, economic and political futures, along with changing human values, add additional long-term uncertainties. It is crucial to therefore identify

FIGURE 10.2

Parties in the water dialogue space



Source: Adapted from Moss et al. (2003, p. 37).

allocation mechanisms that can effectively and flexibly deal with change, uncertainties and the accompanying risks.

The ability to estimate future surface and groundwater availability at different time scales and the inability to predict future water demands and uses are important factors. Arguably, the largest uncertainty stems from the risk of lack of adaptation on the part of institutions to real issues that need to be addressed, and the possibility of water management organizations taking the wrong decisions.

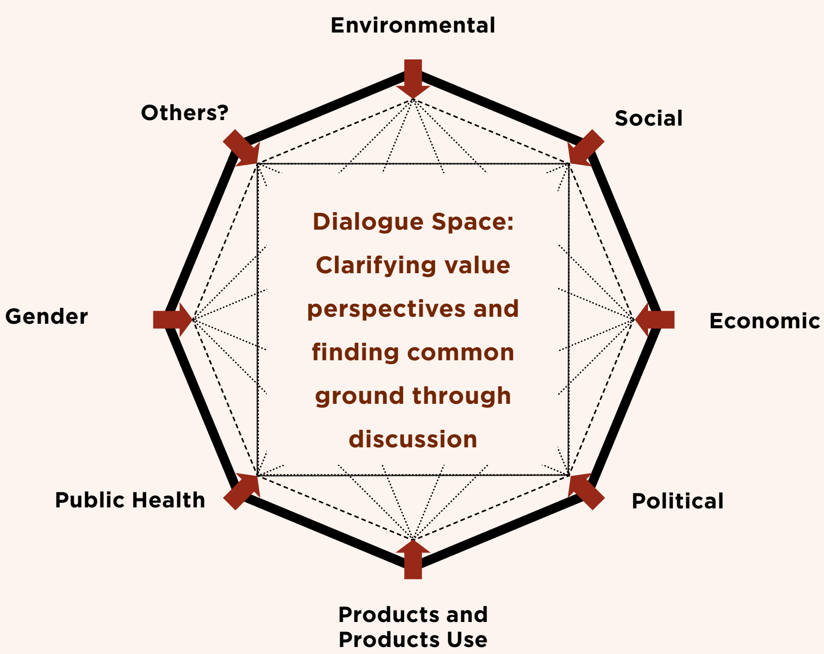
Given these uncertainties, water allocation problems imply four main challenges:

1. How should water be allocated/reallocated in times of shortage and to respond to changes in natural and economic conditions?
2. What solutions are available where rights have been over-allocated and cannot satisfy all holders in times of drought, or where the availability of water from a particular source is subject to long-term decline?
3. How can water institutions evolve to keep pace with and anticipate change?
4. What institutional measures can serve to manage rising tensions that form the source of disputes and conflicts, and how can these tensions be transformed into forms of cooperation?

Effective stakeholder engagement is necessary to make water allocation decisions transparent and fair. Improving the information available to water users is essential but not sufficient to enable them to make the best decisions. Routine stakeholder consultation is not the same as true empowerment, where a community takes control of its water management, leading to more legitimate and cost-effective solutions with better chances of implementation. Fortunately, the experts consulted under the WWAP scenarios project (see Chapter 9) foresee that more information will be made public in the future, and that citizen participation will be more widely practised.

FIGURE 10.3

Value perspectives in the water dialogue space



Source: Adapted from Moss et al. (2003, p. 36).

Notes

1 The exception is consumptive use of water, which evaporates from lakes, reservoirs, trees and crops. (This includes green water, which the WWDR3 [WWAP, 2009, p. 161] defines as 'soil moisture generated from rainfall that infiltrates the soil and is available for uptake by plants and evapotranspiration. Green water is non-productive if evaporated from soil and open water' in the form of rain falling directly onto the land.) Freshwater discharged into the sea, or in a highly contaminated form, is also effectively consumed in the sense that is not available for further beneficial use, except at high cost.

2 In a letter to the Financial Times (7 June, 2010), Jon Lane, Director of the Water Supply and Sanitation Collaborative Council, refers to the fact that more Africans now own mobile phones than toilets. He adds, however, that 'in some countries, a toilet is the new mobile phone – something that shows you've made it'. It is reported that, under the Total Community Sanitation Programme, families in certain communities have decided to categorically reject marriage proposals coming to their daughters from villages where open defecation is practised (Kar, 2003). This exemplifies the recognition of access to sanitation as a sign of health and prosperity.

3 The highest being 191.05.

4 The travel cost valuation method infers the valuation that visitors place on a free amenity from the amount of time and expense they incur in getting to the site.

5 A number of results are reviewed in Turner et al. (2004).

6 If a short-term approach is taken, an assumption is made that capacity is fixed for both alternatives to be compared. In the long term, new investments can be made in either. Marginal and average costs will also differ for both alternatives.

7 The difference between what consumers would be willing to pay, and what they actually have to pay.

References

AICD (Africa Infrastructure Country Diagnostic) (V. Foster and C. Briceno-Garmendia, eds). 2010. *Africa's Infrastructure: A Time for Transformation.* Washington DC, The World Bank/Agence Française de Développement.

Delli Priscoli, J. 2008. *Two Stories.* A presentation at the First African Water Week, Tunis, March 2008.

Dourojeanni, A. and Jouravlev, A. 1999. *Gestión de cuencas y ríos vinculados con centros urbanos.* LC/R.1948. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/8/5668/LCR1948-E.pdf

Emerton, L. and Bos, E. 2004. *Value: Counting Ecosystems as Water Infrastructure.* Gland, Switzerland/ Cambridge, UK, International Union for Conservation of Nature (IUCN).

Granit, J. and Lindström, A. 2009. *The Role of Large Scale Artificial Water Storage in the Water-Food-Energy Nexus.* Stockholm, Stockholm International Water Institute (SIWI).

Grey, D. and Sadoff, C. 2008. *Achieving Water Security in Africa: Investing in a Minimum Platform.* Paper and presentation at the First African Water Week, Tunis, March 2008.

Hutton, G. and Haller, L. 2004. *Evaluation of the Costs and Benefits of Water and Sanitation Improvements at the Global Level.* Geneva, World Health Organization (WHO).

Jouravlev, A. 2003. *Los municipios y la gestión de los recursos hídricos.* LC/L.2003-P. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.eclac.cl/publicaciones/xml/7/13727/lcl2003e.pdf

Kar, K. 2003. *Subsidy or self-respect? Participatory Total Community Sanitation in Bangladesh.* Working Paper No. 184. Brighton, UK, Institute of Development Studies (IDS).

Lentini, E. 2010. *Servicios de agua potable y saneamiento en Guatemala: beneficios potenciales y determinantes de éxito.* LC/W.335. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/0/41140/lcw335e.pdf

Le Quesne, T, Pegram, G. and von der Heyden, C. 2007. *Allocating Scarce Water – A Primer on Water Allocation, Water Rights and Water Markets.* WWF Water Security Series 1. Godalming, UK, World Wide Fund for Nature UK (WWF-UK).

Mays, L. 2006. *Water Resources Sustainability.* New York, McGraw-Hill.

McKinsey & Company. 2009. *Charting our Water Future: Economic Frameworks to Inform Decision-making.* 2030 Water Resources Group. http://www.2030waterresourcesgroup.com/water_full/

Moss, J., Wolff, G. Gladden, G. and Gutierrez, E. 2003. *Valuing Water for Better Governance: How to Promote Dialogue to Balance Social, Environmental and Economic Values?* White paper for the Business and Industry CEO Panel. Calif., Pacific Institute.

Oblitas de Ruiz, L. 2010. *Servicios de agua potable y saneamiento en el Perú: beneficios potenciales y determinantes de éxito.* LC/W.355. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/4/41764/lcw355e.pdf

OECD (Organization for Economic Co operation and Development). 2010. *Benefits of Investing in Water and Sanitation: An OECD Perspective.* Paris, OECD.

Pegram, G. and Schreiner, B. 2010. *Financing Water Resource Management: South African Experience.* A Case Study Report prepared by Pegasys Consultants for the OECD Expert Meeting on Water Economics and Financing, March 2010. European Water Initiative (EUWI) and Global Water Partnership (GWP).

Perry, C. 2007. Efficient irrigation; inefficient communication; flawed recommendations. *Irrigation and Drainage,* Vol. 56, No. 4, pp. 367–78.

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

Saliba, B. C., Bush, D. B., Martin, W. E. and Brown, T. C. 1987. Do water market prices appropriately measure water values? *Natural Resources Journal,* Vol. 27, pp. 617–51.

Salzman, J. 2005. Creating markets for ecosystem services: notes from the field. *NYU Law Review,* Vol. 870. http://www1.law.nyu.edu/journals/lawreview/issues/vol80/no3/NYU302.pdf

Turner, K., Stavros, G., Clark, R., Brouwer, R. and Burke, J. 2004. *Economic Valuation of Water Resources in Agriculture.* FAO Water Report No. 27. Rome, Food and Agriculture Organization of the United Nations (FAO).

UN (United Nations). 2010. *The Millennium Development Goals Report 2010.* New York, UN.

Winpenny, J.T. 1997. Sustainable management of water resources: an economic view. R. M. Auty and K. Brown (eds) *Approaches to Sustainable Development.* London, Pinter.

Winpenny, J., Heinz, I., Koo-Oshima, S., Salgot, M., Collado, J., Hernandez, F. and Torricelli, R. 2010. *The Wealth of Waste: The Economics of Wastewater Use in Agriculture.* FAO Water Report No. 35. Rome, FAO.

World Bank. 2008*a*. *Economic Impacts of Sanitation in the Philippines. Summary.* Research Report published for the Water and Sanitation Programme (WSP). Jakarta, The World Bank.

––––. 2008*b*. *Economic Impacts of Sanitation in Indonesia.* Research Report published for the Water and Sanitation Programme (WSP). Jakarta, The World Bank.

World Commission on Dams. 2000. *Dams and Development: A New Framework for Decision-making.* London, Earthscan.

WWAP (World Water Assessment Programme). 2009. *United Nations World Water Development Report 3: Water in a Changing World.* Paris/London, UNESCO Publishing/Earthscan.

Young, M. and McColl, J. 2009. More from less: when should river systems be made smaller and managed differently? *Droplet,* No. 16, email newsletter, 13 April. Adelaide, University of Adelaide.

CHAPTER 11

Transforming water management institutions to deal with change

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All individuals, agencies and institutions involved in water resources management are very aware that the impacts of decisions they make may not turn out to be the ones they hoped for. Factors that influence the economic, environmental and social benefits or costs resulting from any management decision are not known with certainty. This uncertainty can result in some degree of vulnerability just as much as it may result in higher levels of reliability or resilience. Water managers and their institutions need to recognize the potential consequences of their decisions in uncertain environments, environments where the uncertainty is changing in uncertain ways.

Vulnerability assessments of water resources systems constitute an important basis for water management under conditions of uncertainty and risk.

Leaders in government, the private sector and civil society make most of the important decisions impacting water. It is therefore imperative that they understand the role of water and incorporate this information into their range of decisions. Important instruments to support decision-making include forecasts and scenarios, and combining a range of forecasts of possible futures allows for more robust decision-making. Water management institutions must be created or transformed to reflect this approach.

11.1 Introduction

Sustainable development under conditions of inherent uncertainty requires a paradigm shift. Key factors include the need for an increasing range of input data and the capacity to adapt to growing pressure on the resource. This will require deliberate efforts to build robustness and resilience into the management structures of water projects as a matter of routine. As shown in Chapter 5, such fundamental changes are likely to occur in the non-structural elements of water management measures. In an inherently complex world, leaders in government, private sector and civil society outside the 'water box' take most of the important decisions impacting water. It is therefore important to develop new ways to provide specialized information to decision-makers in government, as well as to those affected by the decisions they take (Falkenmark, 2007). This requires a formal structuring of relationships between technical specialists, government decision-makers and society as a whole (see Figure 11.3, with explanation later in the chapter) (Hattingh et al., 2007; Turton et al., 2007*a*,*b*).

Recent changes in global climate, financial markets, land use and consumption patterns, have increased the uncertainty surrounding future management of water resources. This uncertainty is inherent to the system itself, and relates to the interconnectedness of various systems – hydrological, financial, social and ecological – as well as a general lack of knowledge concerning how an ecosystem might respond to the new demands being made of it. Some now call for a change in thinking away from separate ecosystems and social systems towards socio-ecological systems (SESs) instead (Burns and Weaver, 2008). In this regard it is accepted that human impact is so significant that economic activities and associated social endeavours are no longer seen as being separate from ecosystems – instead social-ecological systems have co-evolved. This is consistent with the emerging notion of the Anthropocene as a potentially new geological epoch (Zalasiewicz et al., 2008). Rather than planning for one defined future, water management agencies increasingly need to improve their methods of assessment in order to respond to a range of possible futures, all of which are uncertain but present varying degrees of probability. Major engineering issues across all possible futures will include planning, designing and operating sustainable, reliable, resilient and non-vulnerable water resource systems, embedded within an increasingly uncertain set of drivers. The ultimate aim should be to inculcate a multi-disciplinary approach to the development of guidelines and regulations for water resources planning, integrating science, economic decision criteria, and monitoring and evaluation processes, all of which should embrace a range of future realities.

As shown in Chapter 5, water management has traditionally been top-down in orientation. *Adaptive water management*, which can be thought of as the management of water resources under conditions of inherent uncertainty, links this to a bottom-up approach. Contemporary experience increasingly shows that a combination of the two approaches is best suited to the core challenge of dealing with uncertainty and risk. A top-down approach, being more strategic in orientation, can provide an overall picture, offering a general framework within which a water management activity or programme can be developed and implemented. A bottom-up approach, being more operational in orientation, can provide an accurate picture of relevant 'on-the-ground' water issues, needs and uncertainties experienced by a wide range of actors and stakeholders. Enthusiasm and support for addressing water-related issues are often best developed at the local level, as this is closest to the point of actual impact, thereby facilitating acceptance of needed actions, provided that it is adequately positioned and has the capacity to effectively deal with the issues.

Developing and implementing an effective water resources management programme ideally incorporates both ends of this management spectrum, specifically as the emphasis shifts from building infrastructure to building institutions (Figure 11.1). However, the relative importance of each approach will vary under differing social, political, economic and environmental conditions. A major challenge for dealing with inherent uncertainties and risks is the introduction of a more adaptive approach to management, irrespective of whether integrated water resources management (IWRM) is adopted as a framework. Adaptive management is based on specific principles and approaches.

11.1.1 Introducing adaptive management to IWRM

IWRM is a globally accepted management framework for achieving sustainable development (Ashton et al., 2006). IWRM has been defined in many ways and the most widely known definition has it not as a tool but as a process. Furthermore, IWRM is a means, not an end in itself, and the process has been very difficult to implement in developing countries, despite some progress, as described in Chapter 1 (Section 1.3.3).

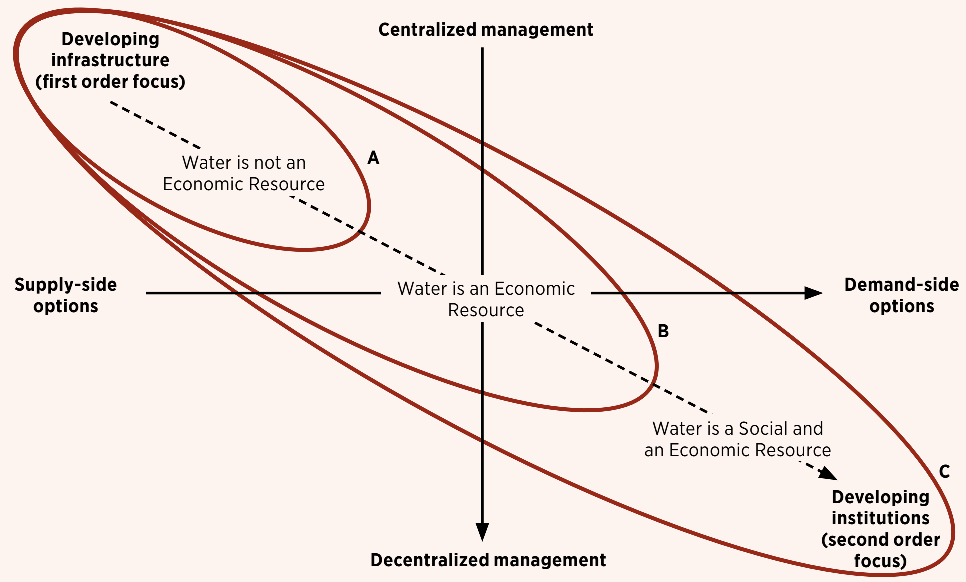
Governance and IWRM are the principal means for resolving competition among multi-sectoral demands on a relatively finite water resources base. Each sector fashions its own set of management principles, rules and incentives that are maximized, often in conflict with one another. Defining social risk tolerance and service reliability is part of a social contract to be determined through a continuing dialogue within each society (Nyambe et al., 2007), whether it be for new drugs, nuclear power plants or water infrastructure. IWRM is contextually shaped through this process to encompass the different dimensions of sustainability (ecological, biophysical, economic, social and institutional), but it is also often path-dependent (see Section 11.4.4). Thus, effective IWRM is knowledge-intensive and needs to be adaptive if it is to continue to respond to exogenous changes over which it generally has little direct control. However, it should also be noted that adaptation can also be identified and adopted without IWRM as the underlying process.

Adaptive management is 'a process that promotes flexible decision-making in the face of uncertainties as outcomes from management actions and other events become better understood' (US National Research Council, 2004). This report describes adaptive management as an approach for keeping up with future changes and making periodic modifications in past decisions in response to those unpredictable changes. It is applicable to situations in which future social, economic, climatic or technological conditions that influence the outcome of any decisions cannot be forecast with certainty.

Absolutely essential for effective adaptive management is a continuing awareness of the changes that are taking place over time, as well as the responses stemming from past decisions. Monitoring, database management and communication are important components of any adaptive management approach. It is an approach that is linked to information about out-of-the-water-box drivers such as economic growth data, population trends and changes in food consumption patterns, mining impacts and demands for energy. Adaptive management is applicable to many aspects of water management, and no less so for responding to flood and drought conditions and their impacts on food production, property damage, and human dislocation and other social impacts. To

FIGURE 11.1

Conceptual model illustrating the general trend of change as water resource managers adapt to include a wider range of drivers and issues



Source: Turton et al. (2007a, fig. 1.1, p. 5, with kind permission of Springer Science+Business Media).

effectively accommodate the 'precautionary principle' (see Section 11.2.3), together with the broader aims of sustainable development, it is necessary to consider the full range of drivers that impact on water infrastructure under a wide range of inherently uncertain supply and demand scenarios. This builds robustness and resilience into water projects by providing flexibility.

11.2 Principles for managing water under risk and uncertainty

In order to meet the goals set by decision-makers, water management must deal with the uncertainty and variability that characterize current changes in the contemporary world. Lempert and Groves (2010) give an indication of the core principles needed to achieve this objective:

- Seek robust projects or strategies, and substantially revise the current economic and optimization decision rules routinely used in water resources management.
- Employ adaptive strategies to achieve robustness; near-term strategies should be explicitly designed to be revised as better information becomes available.
- Use computer-aided processes to engage in interactive exploration of hypotheses, options and possibilities.

These principles are increasingly being advocated by water resource practitioners and academicians, and are manifesting as technological innovations, engineering design changes, multi-objective watershed planning, public participation, regulatory, financial and policy incentives. One example is the emergence of a water accounting framework in Australia (see Chapter 6), designed specifically to integrate reporting across normally disconnected sectors and bureaucracies (AASB, 2011; Godfrey and Chalmers, 2011). Improvements in existing approaches to forecasting are being made using a large number of imperfect but possible future scenarios. These enable analysts and decision-makers to identify a series of near and long-term actions that anticipate a wide range of scenarios, rather than relying exclusively on a single probabilistic forecast of one possible future.

Another key principle is associated with the need to anticipate periods of induced stress brought on by the unanticipated periodic coincidence of high demand and low availability.

Consider some of the options that may help relieve some of this drought stress. In the long run, additional infrastructure can be built to provide added storage capacity, and measures can be taken to reduce leakage in diversion canals and water distribution systems, increase the efficiency of irrigation systems, and provide additional supplies, perhaps through desalination. Alternative sources of energy, such as geothermal, wind and photovoltaic cells, might be developed that use less water than more conventional and more water-consuming alternatives. Short-term options might include demand management measures that reduce human water consumption and increase water reuse.

11.2.1 Diversification as a core principle of adaptive water management

The objective of adaptive water resource management is to enhance resilience by improving the capacity to react appropriately to unanticipated events. These principles, most notably under the broad banner of resilience theory (Burns and Weaver, 2008), are derived from ecosystem theory (Holling, 1973), which argues that diverse systems can better cope with extreme events. An example is the application of portfolio theory, in which investments are made in products of widely differing risk profiles, thereby reducing the overall risk of the total portfolio. Several steps can be taken to diversify water management decisions and investments. For example, in a semi-arid agricultural area that is largely dependent on rainwater, the challenge is to develop new drought mitigation measures, such as increased storage capacity of surface water, increased groundwater capacity, irrigation schemes for local farming communities, satellite technology for precision farming, and new drought-resistant seeds. Water managers would need to advise decision-makers on the policy frameworks necessary to promote such measures, including water pricing policies, subsidies or other financial incentive mechanisms.

11.2.2 Assessing vulnerability

Hashimoto et al. (1982) introduced a taxonomy capable of embracing the risk and uncertainty inherent in water management performance evaluation. They use simple principles that represent a set of descriptors to characterize the key components of the more traditional engineering reliability analysis. In essence they focus on the sensitivity of parameters and decision variables to considerations of uncertainty, including some aspects of strategic uncertainty. These key principles are (Hashimoto, 1982):

- *Reliability*: probability of successful outcomes
- *Robustness*: the satisfactory performance of a system under a range of scenarios
- *Resilience*: how quickly a system recovers from failure (floods, droughts, pollution spills)
- *Vulnerability*: how severe the consequences of failure may be

These five principles expand the key components of more traditional engineering reliability analysis, by focusing on the sensitivity of parameters and decision variables to conditions of uncertainty. Increasing attention is being paid to reducing the structural vulnerability of hydraulic systems by enhancing system resilience as a matter of design. The main question is how to evaluate such strategies? Traditionally, this has been done through risk management on the basis of historical data and statistical analysis, but it is now apparent that past experiences are incapable of predicting future realities, because of the growth of non-linear complexity (Turton, 2007). Strategies are now being selected, for example, using cost–benefit-based risk analysis. The *choice of the discount rate* in economic analysis is an important determinant of the economic viability of a water project, and the level of discount rate appropriate for projects with very long lives, or with strong social or environmental benefits, is the subject of lively debate in engineering circles. The same is true for the level of *acceptable risk* or uncertainty, even if the latter cannot be fully quantified. Supplementary decision-support tools are required when risks cannot be quantified or isolated, as is the case when the many factors described in Chapter 9 interact.

11.2.3 The precautionary principle

The precautionary principle states that if the impacts resulting from an action or policy may cause harm to people or the environment, in the absence of scientific consensus on a probable outcome, the burden of proof that an action or policy is not harmful falls on those taking the action. This implies that decision-makers have a social responsibility to err on the side of caution by protecting the public and the environment from exposure to harm, where a plausible risk has been identified. This is increasingly evident in corporate governance structures found within complex economies, in particular companies listed on various international stock exchanges. These constraints can only be relaxed if subsequent scientific findings emerge providing sound evidence that no harm will occur.

11.2.4 Meeting information needs for management under uncertainty and risk

Reducing the risks associated with water resource management, under conditions of inherent uncertainty, requires a broader set of information inputs. Hydrological data has been often collected for specific purposes, such as the use and design of hydroelectricity schemes, water supply systems and water treatment plants. However, the need for adaptive IWRM places a greater burden on the suppliers of information. The movement of water in time and space is in constant flux, but it is generally managed as if it were a static resource. This approach was possible in the past as demands on the resource were less complex (Turton, 2008, 2010). Today, the web of water dependencies is becoming increasingly complex and the lack

BOX 11.1

Mine closure in South Africa as an example of growing complexity

The city of Johannesburg in South Africa is unusual in the sense that it lacks a river, lake or seashore. Instead, it straddles a continental watershed divide and exists only because of the vast gold resources that lie beneath the city (Turton et al., 2006). These gold-bearing ore bodies consist of pyrite rich in sulphides and are overlain by a massive karst system (Buchanan, 2010). However, the cessation of mining activities is causing the resultant void to fill with highly acidic water, causing some anguish to property owners (Coetzee et al., 2002, 2006). This is driving a degree of uncertainty and constitutes a classic example of the growing complexity confronting water resource managers.

A central issue is calculating the rate of rising water in the void. This requires direct access in order to monitor the water level, however, the companies that control the shafts do not want the data to be made public as they seek to limit their liabilities (Adler et al., 2007). This provides a good example of the need for new types of data previously considered irrelevant to water resource management, as the mine water flows into the headwaters of two major river basins, the Orange and Limpopo, both of which sustain vast socio-economic interests in at least five different downstream countries (Botswana, Mozambique, Namibia, South Africa and Zimbabwe). One of the water resource management challenges is, therefore, establishing how to manage mine closure in situations where limited legislation exists and the absence of cross-sectoral institutional linkages inhibits the flow of needed data (Strachan et al., 2008; van Tonder and Coetzee, 2008).

of accurate information poses a growing challenge for decision-makers, in particular regarding the range of management options including water conservation and demand management strategies. A growing problem is the retention and manipulation of data by commercial entities inaccessible to the public or regulator (Box 11.1). Information may be available in existing government agencies and/or water data sources, but it may also be necessary to initiate monitoring efforts directed to obtaining such data, where it does not currently exist. Monitoring requires extensive instrumentation and transmission capabilities, and demands human capacity; it is also expensive to operate on a sustainable basis. As such, there is mounting pressure in this specific arena (Chapter 6).

11.3 Approaches for managing water under risk and uncertainty

It is useful to differentiate between the vulnerability of a water resources system and societal susceptibility to economic disruptions and dislocation. The vulnerability of a water resources system is a function of the hydrological sensitivity and relative performance of a water management system. The vulnerability of the SES is a function of the sensitivity of the water infrastructure and the resilience of the SES. The two are intimately linked; however, the latter is increasingly manifesting as greater population pressure is placed on a relatively stressed water resource system. The result is a general loss of resilience and a reduction in the margin of error possible before catastrophic failure occurs. This can best be thought of as a general propensity towards vulnerability as greater reliance is placed on an increasingly stressed resource, both as a source and as a sink.

The motivating reasons for making many water management decisions are economic, environmental and social drivers that are not controlled by water managers. Similarly the effectiveness of any water management decisions made is largely determined by these ‘outside-the-water-box’ drivers. Just how vulnerable any decision-making organization may be given the uncertainties of changing drivers needs to be considered when decisions are made. The question to ask when recommending or making decisions regarding water use or water management, especially long-term decisions, is Will a particular decision or development policy be considered a wise or beneficial one, say, 50 years from now? Does it truly fit in to an integrated water resources plan or policy?

It is not easy for water management institutions to adopt an integrated planning and management strategy. Many existing rules and regulations may limit the scope of responsibilities or decisions any given institution can make. Hence one question to ask to check on the degree of integration obtained by some decision by some institution is who is responsible for implementing integrated plans and policies (Box 11.2). Who is responsible for making sure all possible outcomes, and drivers, and affected stakeholders, have been considered in the decision-making process? Who is responsible for looking into the future and judging whether or not some decision will be judged as important for future sustainability? Having answers to these questions is a measure of the extent to which adaptive IWRM has been implemented.

Regularly reviewing these questions will enable adaptations to be made before the challenge is too great to be adequately met by existing institutional arrangements and decision-making processes.

BOX 11.2

Climate Vulnerability Index

People’s vulnerability to global changes is influenced by the quantity of water available now and in the future, underpinned by a range of social, economic and environmental factors. Collectively, these affect the ability to cope with changing conditions. The Climate Vulnerability Index (CVI) is a composite index approach that captures the essence of this definition of vulnerability. This method helps identify to vulnerability in order to prioritize actions to protect local populations. The CVI combines Global Impact Factors (GIFs) including geospatial variables; resource quantification; and information on the accessibility of water and property rights, the capacity of people and institutions, water utilization and the maintenance of ecological integrity. The index values range from 0 to 100, with high values indicating high vulnerability. By developing a range of future conditions, both in terms of climate and socio-economic scenarios, the change in CVI scores from present values indicate how different GIFs will change under different conditions. The CVI has the potential to involve stakeholders, thereby rendering the outcome legitimate and implementable in the eyes of those affected.

Source: Sullivan and Meigh (2005).

11.3.1 Key elements of an adaptive management approach

Adaptive management approaches are slow to evolve, because of increasing uncertainty of future scenarios on the basis of the historical record, in non-linear systems. Consequently, the major challenges facing water resource managers change at unpredictable rates. Failure to respond adequately thus becomes an increasing risk in its own right. A pragmatic 'proactive adaptive management' approach needs to be adopted, comparable to the 'no regrets' philosophy noted in Chapter 5. An adaptive IWRM approach consists of the following elements:

- Strengthened emergency management and preparedness plans for all projects including enhanced public participation and identification of the conditions under which public emergencies requiring special measures will be declared and the limits of such measures (i.e. power and responsibilities of authorities and users)
- Ability to programme the gradual and measured adoption of measures of adaptation and define the threshold which trigger these measures
- An effective information and communications strategy to convey the messages, establish dialogue with allied sectors, influence other sectors' decision-making and rally public support (Nyambe et al., 2007)
- Strengthened inter-agency collaboration for developing joint procedures and applied research for change adaptation
- Risk-based planning and design of infrastructure to account for a defined range of uncertainties
- A new generation of risk-based design standards for infrastructure responding to extreme events (floods and droughts)
- Increased inspections, oversight and regulation of infrastructure during operation, maintenance and life cycle management of aging infrastructure
- Vulnerability assessment of water infrastructure and impact assessment of the socio-economic system in case of failure
- Increased research and development oriented to hydrological change and variability
- Improved forecasting methods
- The process should be reiterative and guided at all stages by common principles

Information and data on water availability and use is inadequate in virtually all countries, irrespective of the state of development. Even where information and data exist, they are often unreliable or fragmented, or may be based on gross estimates. They are usually incompatible both temporally (between periods) and spatially (between countries, water sectors or users, or water basins).

11.3.2 Scenarios as an element of an adaptive management approach

Improvements are being made though an adaptive management approach, involving a range of imperfect forecasts of the future. These rely on many plausible futures, and allow analysts and decision-makers to identify a series of near-term and long-term options that are robust across a wide range of conditions. Rather than relying on a probabilistic forecast of a single future, this approach asks what can be done today to shape a more desirable range of possible futures (Lempert and Groves, 2010; Chapters 8 and 9 of this report.)

There is a need for increasingly sophisticated monitoring systems to source and integrate the necessary data. This adds additional stresses to the overall decision-making process. The need for adaptive management carries with it a fundamental requirement for complex data, hard-wired into feedback loops, specifically for managing the incremental changes needed in the various systems including the means of tracking those changes (Stakhiv and Pietrowsky, 2009). In effect this creates institutional learning as core problems are redefined and new responses are generated through the modified decision-making processes.

11.3.3 Modelling as an element of an adaptive management approach

Systems of locks, dams, levees, irrigation canals and conveyance tunnels were built worldwide before the era of sophisticated modelling and risk and reliability analysis, or the existence of adequate databases for determining risk and uncertainty associated with hydrological variability. Yet those structures still stand and have performed effectively through a wide range of unanticipated supply and demand conditions. In short, they have been remarkably robust and resilient. On the other hand, it is not known how the design specifications based on specific climate parameters will perform under a changing climate.

Every profession has its established customs and standards, and certainly engineers responsible for public safety have theirs. These are partly the result of past practice that seems to be successful or at least acceptable by the public, and partly the result of rules and regulations that engineering contractors need to meet or satisfy to meet legal requirements. An example of such safety standards is the widely used 100-year floodplain that delineates what is susceptible to flooding and what is safe. This is clearly arbitrary and often does not reflect the actual risks of damage involved. Another example is the level of levee protection in the Netherlands, where the range is protecting from a 1,250-year return flow to a 10,000-year coastal storm. Much depends on what the public is willing to pay to be 'safe'.

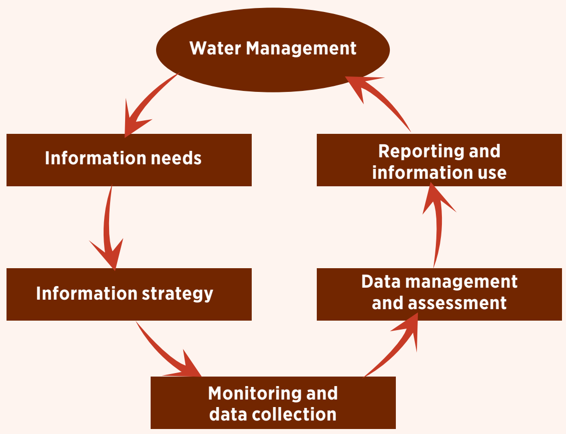
Modelling can help to identify the type and accuracy of data required for decisions being considered. But although the data obtained from current monitoring programmes are intended to be of value to future managers, it is difficult to predict the exact data and precision those future managers may require. The first stage in designing a monitoring system is therefore to define the information needed for the kinds of decisions being made. The information needed determines the attributes to be measured, the types of data to be collected, and the kinds of analyses to be applied.

> Although hydro-climatologic information about frequencies, magnitude, duration and incidence of precipitation and runoff events are the basic inputs into most water management decisions, they are but precursors to more fundamental economic, environmental and socio-economic information and objectives that typically dominate most water management decisions. In fact, it is the non-hydrological information that directs and constrains the basic decision rules that societies use to choose from a range of options that can be employed for any given water management problem. Land-use regulations, economic priorities, trade policies, benefit-cost criteria and even the choice of a discount rate used in deciding the present value of future streams of benefits and costs, are more prominent as decision factors than most hydrologic information. (Stakhiv, 2010, p. 22)

Frequency of measurement and the density of monitoring sites are dependent on the variability of an attribute or parameter's value over time and/or space. Once the monitoring network design has been defined, it is important to specify data collection, storage and analysis procedures, along with plans for reporting and disseminating the results. This is included in the monitoring strategy. These are subject to change and enhancement over time, reflecting changes in knowledge or goals, improvements in methods and instrumentation, and budgets. Actions taken to manage the system more effectively on the basis of monitoring data will lead to changes in information needs. As these change, the monitoring plan is revised accordingly (Figure 11.2) (UNECE, 2006). This approach supports the development of adaptive monitoring programmes that evolve iteratively as new information emerges and research questions change (Lindenmayer and Likens, 2009). This is an inherent property of institutional learning and is an indicator of appropriate adaptive change.

FIGURE 11.2

Monitoring and assessment cycle



Source: UNECE (2006, fig. 3, p. 16).

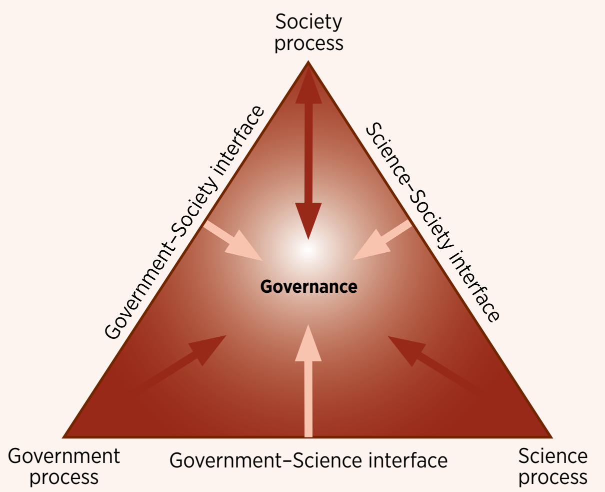
11.3.4 Decision-making that embraces uncertainty and risk

Adaptive IWRM is a sensible and pragmatic approach for modern water managers. It is an extension to IWRM in that it is designed to address the increasing uncertainty inherent to our modern socio-ecological systems (Burns and Weaver, 2008). The natural environment can be considered as 'infrastructure' because it supplies many of the same services as man-made infrastructure. Wetlands assimilate many organic wastes in the same manner as wastewater treatment plants. Soil moisture and groundwater represent significant sources of potential strategic storage. Increased research and monitoring regarding ecosystem water needs helps to optimize use of the natural environment in an infrastructural context.

Water conservation and demand management is an important element of enhanced resource management when set against a backdrop of adaptive IWRM. This requires making trade-offs between various types of water usages to encourage engagement and flexibility. Water management tools for addressing future demands include institutional reforms and policy changes that support demand management and more efficient water use, including the use of appropriate technologies. Appreciation of this approach to managing water resources is important as it embraces behavioural changes and economic and other incentives (Brooks et al., 2009). To be most effective this requires increased public awareness efforts and greater public participation. There is a need for enhanced analytical tools and models yielding results that are credible, understandable and communicable to a broad band of non-technical stakeholders, including the public, the media and political role-players, such as that envisaged by the trialogue approach shown in Figure 11.3 (Ashton et al., 2006; Hattingh et al., 2007; Turton et al., 2007*a*, 2007*b*). Such a multi-disciplinary approach involves stakeholders, psychologists, economists, hydrologists, water resources managers and political scientists, among others, and is increasingly a requirement for deriving optimal infrastructure designs and water-use policies.

FIGURE 11.3

The Trialogue Model with structured interfaces between the three main actor clusters of government, society and science is conducive to adaptive IWRM



Source: Hattingh et al. (2007, fig. 1, © CSIR 2007).

The inability to meet water supply demands and protect people and property against floods and droughts is a significant threat to all countries, but is felt most notably by developing states unable to build the infrastructure needed to reduce the adverse impacts of such events. The reality is that water management systems are not designed to satisfy all demands, given the full range of possible expected extreme events under what is understood to be contemporary hydrological variability. They are designed to minimize the combination of risks and costs of a wide range of hazards to society. This risk-cost balance is constantly adjusted by societies, which is why many countries have flood and drought infrastructure reliability set at a specified-year return period. Of course, as population density and life styles in urban areas increases, these standards invariably change, and begin to approach the risk-averse standards of countries like the Netherlands and Japan. The setting of new design standards and planning criteria are probably the most important aspects of any adaptation strategy.

Water resource management, which is now co-evolving with principles of adaptive management, has employed a variety of tools, in different combinations, to reduce vulnerability, enhance system resiliency and robustness, and provide reliable delivery of water-related services. 'These tools consist of many technological innovations, engineering design changes, multi-objective watershed planning, public participation, regulatory, financial and policy incentives. However, well-functioning institutions are needed to effectively administer this broad array of complex, dispersed and expensive combinations of management measures. Hence, tackling the central issue of governance is a key aspect of any strategy' (Stakhiv, 2010, p. 23) intending to deal with demand change adaptation, and this is a product of adaptive institutions (Falkenmark, 2007; Nyambe et al., 2007; Priscoli, 2007).

11.4 Institutions for managing risk and uncertainty

Present-day water institutions in general are not equipped to deal with contemporary challenges, such as integrating land and water resource management, working towards synergies, ensuring transparency and accountability, acquiring sufficient capacities and resources, and possessing adaptive capacity. Typical mechanisms to deal with uncertainty include establishing watershed services, reducing transaction costs, creating linkages across sectors, and developing a new leadership style.

Improving institutions entails strengthening institutional capacity, creating learning-oriented institutional processes, tackling institutional deficits, and incorporating informal institutions into water management. This implies fostering the capacity to work outside the water box in a way not yet common in mainstream practice.

Institutional capacity needs to encompass a clear definition of the roles and responsibilities of each authority, particularly in cases of emergencies or slow-onset disasters. Important features of adaptive institutional capacity are: clear decision-making procedures, communication protocols and contingency planning, sustained by regular training and simulation exercises (UNECE, 2009; WWAP, 2009).

Conventional water planning tends to be rigid and water institutions are typically poorly linked to other institutions required for effective governance of the water resource and services (Funke et al., 2007). The collective challenge is to ascertain how to develop adaptive governance frameworks and institutions, in response to growing calls for attention to more resilient institutions and approaches (GWP, 2009). Recent developments in water management focus on improved governance and institutional changes, including changes within formal and informal domains, as well as the shifting boundaries of the public/private divide (Falkenmark, 2007; Priscoli, 2007; Nyambe et al., 2007). While some countries have made significant improvements, the success of institutional reform has been mixed, with many countries still facing governance, financial and capacity shortcomings to implement new institutional structures (Box 11.3).

11.4.1 Creating adaptable and flexible institutions

Recognition that IWRM (see Section 5.1) needs to become more adaptive has brought increased appreciation for multi-sector and multi-disciplinary collaborative efforts towards sustainable development. This provides an opportunity for healthy institutional change. Without institutions capable of accommodating uncertainty, climate and other external changes will impose significant costs on water users and water-dependent communities, ultimately limiting economic growth potential. Identifying the way that endogenous and exogenous features influence management processes enhances adaptive institutional architecture and effectiveness. The key challenges to sustain healthy institutional evolution are as follows.

Integration

This includes the alignment and integration policies within the formal and informal institutions that regulate actions for both land and water. Effective institutions encourage cost-effective conservation measures and efficiency enhancements, like water-demand management practices, while remaining flexible and adaptable enough to accommodate increasingly uncertain climate forecasts. They also need to be robust enough to accommodate changes in water availability by facilitating the reallocation of water supplies, which is an action prone to the generation of instability, if incorrectly managed. When integration cannot be achieved, trade-offs may be necessary and

BOX 11.3

Water quality monitoring in Nigeria

The goal of water-quality monitoring is to obtain information useful for managing water resources. In Nigeria, most of the water used for domestic and industrial purposes is channelled from rivers and groundwater. The majority of the populace obtains water from rivers and shallow wells, and constant water-quality monitoring is a way to check and avert pollution, as well as upgrade standards. This is most practical in cities where high population density and industries result in the discharge of a large amount of waste into water bodies. Water-quality monitoring in Nigeria only involves the monitoring of groundwater levels once a year in each state, and is performed by the state water board using standards established by the Federal Environmental Protection Agency of Nigeria. There is no integrated river water-quality-monitoring scheme. Although the environment is characterized by unfavourable legislative, technical and operational conditions, the principal constraints on water-quality monitoring in Nigeria are institutional barriers: the organizational framework does not function in a way to enable such monitoring. The key issues include inadequate and untimely funding, shortage of requisite personnel, lack of a central coordination body for agency activities, poor maintenance of infrastructure, and lack of response to institutional reform needs. As a result, there are only mild or even no penalties for culprits. Moreover, the lack of information on pollution is a serious hindrance to pollution management. Monitoring is not just a technical issue; it is also an organizational and institutional issue.

Source: Ekiye and Zejiao (2010).

synergies can be sought, to achieve resource optimization and minimize adverse impacts. A key challenge is how to engage unregulated traditional and informal institutional frameworks with formal water supply regimes.

Realizing synergies

Different institutions may take measures that influence each other. For example, the European Union (EU) Common Agricultural Policy (CAP) plays a beneficial role in achieving the goals of the EU Water Framework Directive (WFD). Such synergies are beneficial for at least one of the institutions. Identification of weak or strong links between institutions helps to identify possibilities for synergies (or avoidance of disruption), delineate reform tasks, and set institutional priorities (Wettestad, 2008). Similarly, policies implemented by agencies responsible for mining in water-constrained areas might benefit society at large, but have severe negative impacts on national food security, because of the unintended consequence of unplanned mine closure, such as is the case in South Africa (van Tonder and Coetzee, 2008).

Water integrity and accountability

Transparent processes and access to information are required to discourage corruption, which adversely affects efficient and equitable water allocation and the delivery of water and sanitation services – particularly to poor and vulnerable groups. Corruption is a symptom of a governance crisis that increases transaction costs (Allen, 1999; Lund, 1993) and discourages investments (Earle, 2007). Hence, it affects institutional reform for improved accountability (Marin et al., 2007). In most developing countries, regulators tasked with these specific roles are often weak and are sometimes absent (van Wyk et al., 2007). Water accounting is now starting to emerge in water-constrained countries, like Australia, driven by the need to improve the integrity of reporting on water usage by all stakeholders (AASB, 2011; WWAP-UNSD, 2011).

Capacity development and resources

Adequate financing and appropriate staffing are required for effective and efficient delivery of water services, and the ability and authority to address basic governance issues like integrity and accountability. One emerging example comes from the Mapungubwe area in the Limpopo River Basin, where the government has allocated mining rights without consideration for water constraints and cultural sensitivities in the adjacent UNESCO World Heritage Site. The outcome of a process of vigorous contestation was a new agreement between the mining industry, government and wildlife conservationists, to create a new form of offset trading to meet the requirements of all parties.[1]

Adaptive capacities of institutions to deal with risk and uncertainties

Developments in technology and infrastructure, as well as the availability of financial resources, will be essential to improve water-use efficiency.

An example is found in the new coal fields in the Greater Soutpansberg (portion of the Limpopo River basin), where endemic water scarcity is a fundamental constraint to job creation through mining. One solution under investigation involves the creation of what is known as a special purpose vehicle (SPV) by the DWA, which would facilitate the buy-out of the existing water rights of farmers, along with the negotiation of an off-take agreement with the mining sector. This is an example of adaptive management, where government plays a proactive role in shifting water from an activity with a known low sectoral water efficiency (SWE) ratio (agriculture) to one with a known high SWE (mining).

Generating adequate and sustainable financing

Many water institutions in developing countries are plagued by under-financing and capacity deficits. New funding is required for more effective institutional implementation, but existing funding should be used more efficiently. Most water funding goes to infrastructure development rather than being invested in developing institutions and human capacities. Governments and the private sector must provide better incentives for innovative funding approaches that can enhance institutional implementation, and thus reduce the uncertainties affecting people's livelihoods, as well as access to water resources and services.

Another mechanism is to *reduce free-riding* and transaction costs (Nicol et al., 2001). Water resource institutions determine who can use what water, how, at what time and for how much; they also set management responsibilities, tariffs and collect fees. To keep an institution viable the various members need to contribute financially. Free-riding occurs when legitimate water users take more than their allocated share of water, which can trigger disputes over allocation. Water resources may also be extracted by illegitimate users without legal rights, permits or entitlements to that specific resource, which is especially common and difficult to control in the case of groundwater. For that reason, community-based water supply projects in rural areas have frequently proved untenable, with many communities unable to raise sufficient funds to meet operation and maintenance costs associated with common water resources. The transaction costs for monitoring and policing water users can be so high that it outweighs the benefits, particularly in rural areas where water users can be dispersed over large areas. This may also be the case if community goals of fairness in water allocation and cost-sharing are deficient. Social sanctioning may minimize the number of free-riders (Clark, 1977; Olson, 1965). Social norms can generate punishment for community members who break the rules, and run the risk of social exclusion or disrespect (Breier and Visser, 2006; Ostrom, 1990).

BOX 11.4

Review of water management institutions and reforms in 11 countries

A review of 11 countries – Mexico, Chile, Brazil, Spain, Morocco, Israel, South Africa, Sri Lanka, Australia, China, and India, undertaken by Saleth and Dinar (1999) – suggests that among the 11 countries, only Australia and Chile (and within the United States of America, California and Colorado) are at an advanced (though not ideal) stage of institutional change.

'Some of the recommendations from this study on institutional changes include:

- Attempts to fix isolated parts of water management will influence other dimensions. An integrated approach is best, at the heart of which should be institutional changes aimed at modernizing and strengthening legal, policy and administrative arrangements for the 'whole spectrum of water management.
- Institutional changes taking place everywhere suggest that the opportunity costs of (and net gain from) institutional change are overtaking most transaction costs. But institutional change is not uniform, suggesting that opportunity and transaction costs vary.
- Funding agencies should focus efforts and resources in countries, areas, and subsectors that already have enough critical mass in institution-building to ensure success and lower transaction costs.
- The sequence and pace of reform should reflect realities of scale economies and political pressures from reform constituencies. When possible, political economy should be exploited to quicken reform.'

Source: Saleth and Dinar (1999, from the summary findings).

The raising of capital to overcome some of these constraints has a rich history. The Swayam Shikshan Prayog project in India has facilitated the formation of more than 1,000 women's savings and credit groups, which have mobilized their own capital to provide loans for one another. The Sakhi Samudaya Kosh was established as a non-profit organization in 2006 to provide micro-credit for women for agriculture, water and sanitation, as well as insurance to low-income people in disaster areas.[2] The Grameen Bank is another example, which has been shown to be highly effective to the point that it was jointly awarded the Nobel Prize in 2006.[3]

11.4.2 Actions which can improve institutions

Institutional changes within water management occur due to endogenous factors (water scarcity, performance deterioration and financial non-viability) as well as exogenous factors (macro-economic crisis, political reform, natural calamities and technological progress). Together, these raise the opportunity costs of institutional change, reduce the corresponding transaction costs, and create an institutional culture that is conducive to reform. Box 11.4 provides recommendations that can be useful in mobilizing the mutually supportive aspects of these factors for institutional reform.

Institutional water management is most effective when based on collaborative governance. Water management that builds on a joint effort of government, society and technical institutions ensures that measures will be both effective and sustainable (Hattingh et al., 2007; Turton et al., 2007). This entails looking outside the water box and improving disciplinary integration over diverse aspects such as water, agriculture, mining, environment, planning, finance and rural development, on both technical and policy levels. Achieving this will require the building of trust and social capital (Fine, 2001; Ostrom, 1994, 2001) to ensure that a problem-solving process takes place (Timmerman et al., 2010).

Institutional reform needs to be firmly anchored among stakeholders and their leadership. If institutions do not have legitimacy in the eyes of the public, they will not receive support and stakeholders are more likely to retain the *status quo*, or even develop their own informal rules, thereby undermining the integrity of the system. An important mechanism is therefore to improve institutional performance by improving political will and leadership. This remains a challenge for water decision-makers.

> "Transparent processes and access to information are required to discourage corruption, which adversely affects efficient and equitable water allocation and the delivery of water and sanitation services – particularly to poor and vulnerable groups."

The basis of any serious and workable system of dispute resolution is the existence of an independent administrator or judiciary with compulsory jurisdiction over the conflict to adjudicate, should every other means fail. Otherwise the party benefiting from the status quo has no incentive whatsoever to submit to any other means of (voluntary) dispute resolution.

Effective institutional change, and the degree to which this can deal with inherent uncertainty, is closely related to *path dependence*. In its simplest form, path dependence explains how current situations facing water decision-makers for any given circumstance, are generally defined by past decisions, even though the past circumstances may be irrelevant in the present and future. Because of the path dependence of water institutions in general, it is important that water decision-makers intensify their efforts to provide incentives for meaningful institutional change, by adopting the following measures.

Reinforce water institutions: Addressing implementation challenges, such as vested political interests and accountability systems, before any new institutions are put in place, helps to strengthen those institutions. Many countries are plagued by implementation problems driven by a lack of human capacity, information flows and financing. The fundamental governance issues that generate disincentives for enforcement by water institutions, and appropriate institutional set-up, generally remain intractable. Within governance systems characterized by the existence of a patron/client relationship, corruption and vested political interests tend to endure. Changing decision-making practices so that they are transparent and accountable will be more effective than increased capacities and better scientific information under these circumstances.

Create learning-oriented institutional processes: Experience suggests that institutional reform is an iterative learning process, where change is negotiated between different groups. There are no perfect solutions, only solutions that work in a particular context, so the best fit is often more important than the best practice (Baietti et al., 2006).

Fostering dialogue and consensus at the national level is an essential element for success, ensuring the full involvement of all sectors of society.

Address institutional deficits: The institutional set-up in areas responsible for water quality and groundwater management is often very limited. Sustainable management of these areas is likely to become more relevant with changing demographics, socio-economic developments and climate change.

Go beyond formal regulation and incorporate informal institutions into risk and uncertainty analyses: Informal local institutions allocate water resources in many parts of the world, and formal regulatory systems may only have limited influence on such decisions. A major challenge is to reach poor and marginalized social groups that normally depend on informal systems of water allocation and service delivery.

Looking beyond what is traditionally considered water management – going outside the water box – is therefore inevitable. Connecting water management with land management and sectors like agriculture, mining and energy, at the institutional level, will enhance the probability of effective decision-making (Ashton et al., 2006). Realizing this approach is highly demanding on leadership, and overcoming the inertia of traditional approaches and resistance from various actors remains a daunting task. Decision-makers need support in putting these ideas into practice, as well as the courage to withstand criticism, and the willingness to share power with other actors. Previous experience has shown that those who champion policy change often become victims of the very process of change that they successfully initiate (Huitema and Meijerink, 2009).

11.5 Communicating risk and uncertainty

In order to make appropriate decisions to manage particular uncertainties and risks, the uncertainties and risks involved first have to be clearly understood. Events carrying a low probability of risk (e.g. an aeroplane crash or nuclear plant leak) are often feared more than those carrying a higher probability of risk (e.g. being hit by a car while walking or cycling). Without precise information expressed in a clear and concise way, the magnitude of any risk or uncertainty involved in an action is easy to misjudge. Mistakenly attaching excessive risk to events may not only cause unnecessary anxiety, but may also cause individuals to put themselves in the way of harm (Thaler and Johnson, 1990). Uncertain situations have uncertain outcomes and therefore carry a degree of the unknown, which if communicated inadequately can cause exaggerated worry or fear. It is therefore important to supply enough accurate information to give the individual a certain amount of control when faced with uncertainty. This can make managing uncertainty less stressful and, as a result, attain more positive and realistic outcomes.

11.5.1 Media influence

It is all too easy to negatively communicate uncertainty, as can be frequently observed in the media. High levels of uncertainty can give those who aspire to a particular agenda an opportunity to 'spin the facts' and communicate in a deliberately misleading or manipulative way, often causing worry or fear. If the objective is to motivate people into positive action, communicating in this manner, commonly used as a method of control, be it political or otherwise, can be largely counterproductive, generating a climate of fear and feelings of helplessness.

The task of covering an issue in a balanced and responsible way presents an obvious challenge for members of the press and the media in general. This is especially true in situations where statements about uncertainties can be immediately seized upon and interpreted in different and conflicting ways in ongoing public debates.

Uncertainty can also offer crucial opportunities for generating benefits, and it is important to find, where possible, ways of communicating uncertainty that are empowering and constructive and that highlight the possible benefits.

Another area that can cause confusion when communicating uncertainty and risk – and indeed when communicating in general – comprises the numerous different voices or opinions, expert or otherwise, that are put forward. If conflicting arguments or opinions are being expressed by what are considered to be reliable and reputable sources – such as trusted media organizations, experts, government agencies or respected personalities and journalists – the resulting situation rapidly creates confusion in the eyes of the general public.

Individuals or groups may have different reactions to conflicting information: some may choose to accept an opinion that most suits their lifestyle/belief system, some may delve deeper – if they are interested enough – and commit to further research on which to base a more informed opinion. Others may be unable or unwilling to make sense of the conflicting opinions and may be discouraged by the topic altogether: 'you can't believe what you hear'.

In order to face the global changes and challenges that lie ahead, a concerted effort by the water community to communicate in one voice – a strong and collective voice – is a priority, especially if it is to encourage leaders and decision-makers and stakeholders from all walks of life to cooperate and act in the best interests of all. The importance of expressing important information coherently and in a coordinated manner should not be underrated.

11.5.2 Deciphering uncertainty and risk

Specialists and non-specialists alike constantly manage uncertainty and statements of probability. While errors in detail can be made, many people succeed in managing non-technical probabilistic information about the likelihood of events, such as river flows, lake levels, weather events, water shortages, floods and pollution levels. Communicating aspects of uncertainty and risk can be a particular challenge when the nature of the decisions being debated is largely technical. Decision-makers other than water managers, including users, politicians, leaders and the general public, all of whom participate in modern water management decision-making at some level, sometimes have difficulty fully understanding standard technical concepts, such as those concerning a 100-year floodplain or a category 5 hurricane storm surge. Explaining various aspects of the uncertainties and unknowns associated with non-stationary phenomena to the decision-making public becomes even more demanding. The challenge is how to most effectively help the public, stakeholders and decision-makers to understand uncertainties and their impact on possible decisions, thereby enabling them to be better informed as they participate in debates over which decisions are best. One of the aims is therefore to express probabilistic information and expert opinion in transparent non-technical and recognizable terms.

Bridging the gap between scientific research and decision-makers is the key to change. Communication plays a large part in the decision-making process and should not be underestimated.

The extremes and changes currently being experienced are still mostly within the norms of natural historical climate variability. Much of today's existing water resources infrastructure was designed to accommodate order-of-magnitude of variability. Standard engineering practices account for uncertainties by including redundancy (safety factors) in designs. It is also imperative for anyone involved in setting flood and crop insurance rates, defining floodplain zones, and designing levees, reservoirs, storm sewers and highway culverts, for example, to understand these risks and uncertainties and their possible economic, environmental, and social consequences.

Most people prefer certainty to uncertainty. They would much rather be told that it is going to rain today, or that it is not going to rain today, or that their flight will depart on time, than being told that there is a 64% chance of getting wet, and consequently there is a small chance of a flight delay, even if they know that these definitive statements may not be true. If the statements turn out to be false, clearly some trust between the forecaster and the public will be lost. People's responses to uncertainty partly depend on their attitude towards what is uncertain, such as a flood hazard. Those desiring more certainty will not be satisfied, and those who had intended to ignore the hazard may become even less concerned about it because if there is a substantial risk of harm related to some possible event, it is no doubt wise to make sure the public knows what that harm might be, even if the probability of that event and hence the risk might be low.

The same applies to warnings and reassurances. The temptation to suppress uncertainty and express confidence is ever present, but it is best if the temptation is resisted. If over-confidence proves to be misplaced it damages credibility and the ability to communicate effectively. If possible, people should be told what is certain, what is almost but not quite certain, what is probable, what is a gamble, what is possible but unlikely, and what is almost inconceivable. Bounds can be placed on the uncertainty: uncertain risks can be expressed in terms of the range of expert opinions. The greater the uncertainty, the more justified the precautions, precisely because the risk could be more serious.

It should be acknowledged by all those making estimates of, or trying to quantify, risk and uncertainty that these estimates or quantitative measures are themselves uncertain. For example, just how confident is it possible to be that the probability of rain today will be 10%? This higher level of uncertainty just complicates the communication of risks and uncertainties, but it is there, even if it is not known. Those who wish to wait before saying anything about a risk level until they know how confident they are of their risk predictions may never have anything to say.

BOX 11.5

Gender-sensitive dissemination of information: The case of early warning systems in Bangladesh

Men and women access, process, interpret and respond to information in different ways, due to the cultural context and gender division of labour. Statistics from past disasters around the world demonstrate the consequences of gender-neutral early warning systems. In 1991, for example, the death toll from the Bangladesh cyclone was five times higher for women than men, partly because early warning information was transmitted by men to men in public spaces, rarely reaching women directly. Early warning systems that are 'gender neutral' are not effective in reaching women adequately, and thus preparedness is limited and may ultimately cost lives. A gender-sensitive approach enhances early warning systems through: monitoring and warning services; dissemination of information by media that can reach women; and response capability. Women play an important role as first responders in taking appropriate and timely action in response to the warnings.

Source: UNISDR, UNDP and IUCN (2009).

Communicating uncertainty is a good start, but it is not enough. The goal is to communicate what is presently thought, or known, as precisely as possible, and to communicate the level of uncertainty.

An easy way to specify degrees of uncertainty is with numbers. The odds of '1-in-a-million' means it is practically not going to happen; '1-in-100' means it is highly unlikely but could happen; and '1-in-10', although less unlikely, would still surprise most people if it occurred. Similar estimates at the other end of the probability distribution include '9-in-10', '99-in-100', and '999,999-in-a-million'. When '50-50' is used it helps to clarify whether the evidence is generally evenly divided, or that there is no relevant evidence on which to base a judgment. When deciding on the consequences of risk, decisions often largely depend on the context (e.g. what is at stake): an engineer may not take a 1-in-10 risk in engineering design, but may leave an umbrella at home if the likelihood of precipitation is 1-in-10.

Other, longer phrases that can communicate different levels of uncertainty reasonably clearly are as follows (Sandman, 2004):

- 'The weight of evidence suggests that X is likelier than not, but there is still plenty of room for doubt.
- We're almost sure that X is not happening, and are proceeding on that assumption, but are continuing to monitor the situation to allow ourselves to change course should it be mistaken.
- We think it is probably X or Y and would be shocked at anything else; although Z is less likely it remains a possibility.'

11.5.3 Targeted communication

When ideas are expressed (e.g. 'more effectively addressing risks creates benefits and reduces vulnerabilities'), they can often seem intangible. As such, they can be easy to agree with, but difficult to know how to achieve. Effective communication breaks down the global statement/aim into smaller sections to make it more easily understood. Questions can be asked such as 'How can that goal best be attained?' 'What are the practical steps that could be taken to achieve that goal?' 'Who could meaningfully contribute to reaching the goal successfully?' and 'How could they do this?

Separating the audience into target groups and tailoring the communication to each can clarify and strengthen the impact of the message. A target group of high importance is the media, in all its various forms. Many crucial messages are imparted through the media, whether expressed negatively or positively. The media is a powerful communicating force both at local and global levels, and influences opinions – and therefore actions – in a vast array of topics. Typically the media need 'hooks'. Generally the more dramatic the 'hook', the more likely it is that the information will be published or broadcast (e.g. a shocking statistic may make headlines while a competing positive statement about the same topic may not). It is important to strike a balance between attracting the media, while being aware of and taking responsibility for the possible impact of the information fed to them.

In order to motivate a target audience with targeted messages it is important to clearly define each group and understand their motivation. How each group responds to communication and acts upon its message is also likely to be different. What motivates political leaders to act in the face of uncertainty may be different from what motivates teachers or small business owners. As there are multiple angles to information and as the reference point, coding and editing of particular messages are key factors in the analysis of decisions (Kahneman and Tversky, 1979) in order to achieve the desired communication objective the correct angle, key words and language should be chosen carefully and correctly for each target group (see Box 11.5).

Profile questions can be asked to identify what motivates each group. This requires some generalization, and it is important to be certain when correctly identifying the characteristics of a particular group (avoiding stereotypical identifiers). This is particularly pertinent if the target group is *not* the one to which the profiler belongs. A diverse group should therefore carry out this activity to ensure broader social knowledge and awareness. Examples of questions that can be asked of each group are:

- What is their average level of education?
- Which newspapers/magazines do/may they buy?
- What motivates them to make particular purchases/take particular action?
- What do they consider as worrying on a local/global scale?
- What action can they/would they *be likely* to take? What inhibits them from taking this action?
- What do *they/others* consider to be their weaknesses and strengths?

Once the target audiences have been defined and their motivations and desires better understood, it is easier to communicate information effectively. It is not important if the communication material prepared for one target audience is not understood by all target audiences, but it is important that it is understandable to the particular group being addressed. The language used in targeted communication can be stronger and clearer as it does not attempt to 'cover all bases'. The more familiar the language, the easier it is for that specific group to understand. For example, technical information and data may be used in abundance for one target group but greatly modified or used sparingly for another.

To maximise effectiveness in terms of positive action when communicating uncertainty and risk, it may be necessary for each target group to feel reasonably challenged (a percentage of shock factor may be necessary), but not fearful or helpless.

Conclusion

Instead of imparting an impression of impending doom or disaster, uncertainty and risk can instead be communicated through targeted, precise and enabling messages, with communicators bridging the gap between experts (who may be largely technical) and the general public. When communicating through the media or otherwise, it is important to highlight the fact that uncertainty and risk can also bring opportunity and the possibility of positive change.

Knowledge is empowering and forms the basis for making informed and progressive decisions, and information communicated in a clear and targeted way, with one voice, can enable people to better understand, and reach their own conclusions, about the risk involved. This in turn imparts responsibility and encourages action, which is essential for change.

Notes

1 For more information see http://www.savemapungubwe.org.za/media.php

2 For more information see the Swayam Shikshan Prayog Project website http://www.sspindia.org/

3 For more information see http://en.wikipedia.org/wiki/Grameen_Bank

References

AASB (Auditing and Assurance Standards Board). 2011. *Consultation Paper: Assurance Engagements on General Purpose Water Accounting Reports.* Melbourne, AASB.

Adler, R. A., Claassen, M., Godfrey, L. and Turton, A. R. 2007. Water, mining and waste: an historical and economic perspective on conflict management in South Africa. *Economics of Peace and Security Journal,* Vol. 2, No. 2, pp. 32–41.

Allen, D. 1999. Transaction costs. *Encyclopedia of Law and Economics.* Cheltenham, UK/Ghent, Belgium, Edward Elgar/University of Ghent, pp. 893–926. http://encyclo.findlaw.com/0740book.pdf.

Ashton, P. J., Turton, A. R. and Roux, D. J. 2006. Exploring the government, society and science interfaces in integrated water resource management in South Africa. *Journal of Contemporary Water Research and Education,* Vol. 135, pp. 28–35.

Baietti, A., van Ginneken, M. and Kingdom, W. *Characteristics of Well-Performing Public Water Utilities.* 2006. Water Supply and Sanitation Working Notes, no. 9. Washington DC, The World Bank.

Breier, M. and Visser, M. *The Free Rider Problem in Community-Based Rural Water Supply: A Game Theoretic Analysis.* 2006. Southern Africa Labour and Development Research Unit (SALDRU) Working Paper Number 06/05. Cape Town, South Africa, University of Cape Town.

Brooks, D. B., Brandes, O. M. and Gurman, S. (eds). 2009. *Making the Most of the Water We Have: The Soft Path Approach to Water Management.* London, Earthscan.

Buchanan, M. (ed.) 2010. *The Karst System of the Cradle of Humankind World Heritage Site: A Collection of 13 Issue Papers by the South African Karst Working Group.* Pretoria, South Africa, Water Research Commission (WRC).

Burns, M. J. and Weaver, A. v. B. (eds). 2008. *Advancing Sustainability Science in South Africa.* Stellenbosch, South Africa, Stellenbosch University Press.

Clark, C. W. 1977. The economics of overexploitation. G. Hardin and J. Baden (eds) *Managing the Commons.* San Francisco, Freeman, pp. 82–95.

Coetzee, H., Wade, P. and Winde, F. 2002. Reliance on existing wetlands for pollution control around the Witwatersrand gold/uranium mines of South Africa – are they sufficient? B. J. Merkel, B. Planer-Friedrich and C. Wolkersdorfer (eds). *Uranium in the Aquatic Environment.* Berlin, Springer, pp. 59–64.

Coetzee, H., Winde, F. and Wade, P. 2006. *An Assessment of Sources, Pathways, Mechanisms and Risks of Current and Potential Future Pollution of Water and Sediments in Gold Mining Areas of the Wonderfonteinspruit Catchment.* WRC Report No. 1214/1/06. Pretoria, South Africa, Water Research Commission (WRC).

Earle, A. 2007. The role of governance in countering corruption: an African case study. *Water Policy,* Vol. 9, No. 2, pp. 69–81.

Ekiye, E. and Zejiao, L. 2010. Water quality monitoring in Nigeria: Case study of Nigeria's industrial cities. *Journal of American Science,* Vol. 6, No. 4, pp. 22–8.

Falkenmark, M. 2007. Good ecosystem governance: balancing ecosystems and social needs. A. R. Turton, H. J. Hattingh, G. Maree, D. J. Roux, M. Claassen and W. F. Strydom (eds) *Governance as a Trialogue: Government–Society–Science in Transition.* Berlin, Springer-Verlag, pp. 60–79.

Funke, N., Oelofse, S. H. H., Hattingh, J., Ashton, P. J. and Turton, A. R. 2007. IWRM in developing countries: lessons from the Mhlatuze catchment in South Africa. *Physics and Chemistry of the Earth,* Vol. 32, pp. 1237–45.

Fine, B. 2001. *Social Capital Versus Social Theory: Political Economy and Social Science at the Turn of the Millennium.* London, Routledge.

Godfrey, J. and Chalmers, K. (eds) 2011. *Water Accounting: International Approaches to Policy and Decision Making.* London, Edward Elgar.

GWP (Global Water Partnership). 2009. *Institutional Arrangements for IWRM in Eastern Africa.* Policy Brief 1. Stockholm, GWP.

Hashimoto, T., Stedinger J. R. and Loucks, D. P. 1982. Reliability, resiliency, and vulnerability criteria for water resource system performance evaluation. *Water Resources Research,* doi:10.2166/wp.2007.130

Hattingh, J., Maree, G. A., Ashton, P. J., Leaner, J. J. and Turton, A. R. 2007. A trialogue model for ecosystem governance. *Water Policy,* Vol. 9, No. 2, pp. 11–18.

Heyns, P. S. V. 2007. Governance of a shared and contested resource: a case study of the Okavango River Basin. *Water Policy,* Vol. 9, No. 2, pp. 149–67.

Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics,* Vol. 4, pp. 1–23.

Huitema, D. and Meijerink, S. (eds) 2009. *Water Policy Entrepreneurs: A Research Companion to Water Transitions around the Globe.* Cheltenham, UK, Edward Elgar.

Kahneman, D. and Tversky, A. 1979. Prospect theory: an analysis of decisions under risk. *Econometrica,* Vol. 47, No. 2, pp. 263–91.

Lempert, R. J. and Groves, D. G. 2010. Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American west. *Technological Forecasting and Social Change,* Vol. 77, No. 6, pp. 960–974. http://www.sciencedirect.com/science/article/B6V71-506SX76-1/2/6b7303c489efa3d9254714a083d81045

Lindenmayer, D. B. and Likens, G. E. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. *Trends in Ecology and Evolution,* Vol. 24, No. 9, pp. 482–86.

Lund, J. R. 1993. Transaction risk versus transaction costs in water transfers. *Water Resources Research,* September, Vol. 29, No. 9, pp. 3103–7.

Marin, L. E., Sanchez Ramirez, E. and Martinez, V. 2007. The role of science in improving government accountability to society. *Water Policy,* Vol. 9, No. 2, pp. 113–25.

Nicol, A., van Steenbergen, F., Sunman, H., Turton, A. R., Slaymaker, T., Allan, J. A., de Graaf, M. and van Harten, M. 2001. *Transboundary Water Management as an International Public Good.* Stockholm, Ministry for Foreign Affairs.

Nyambe, N., Breen, C. and Fincham, R. 2007. Organizational culture as a function of adaptability and responsiveness in public service agencies. A. R. Turton, H. J. Hattingh, G. A. Maree, D. J. Roux, M. Claassen and W. F. Strydom (eds) *Governance as a Trialogue: Government–Society–Science in Transition.* Berlin, Springer-Verlag, pp. 197–214.

Olson, M. 1965. *The Logic of Collective Action. Public Goods and the Theory of Groups.* Cambridge, Mass., Harvard University Press.

Ostrom, E. 1990. Governing the Commons: *The Evolution of Institutions for Collective Action.* Cambridge, UK, Cambridge University Press.

––––. 1994. Constituting social capital and collective action. *Journal of Theoretical Politics,* Vol. 6, No. 4, pp. 527–62.

––––. 2001. Social capital: a fad or a foundation concept? P. Dasgupta and I. Serageldin (eds) *Social Capital: A Multifaceted Perspective.* Washington DC, The World Bank, pp. 172–214.

Priscoli, J. 2007. Five challenges for water governance. A. R. Turton, J. Hattingh, G. Maree, D. J. Roux, M. Claassen and W. F. Strydom (eds) *Governance as a Trialogue: Government–Society–Science in Transition.* Berlin, Springer-Verlag, p. xxix.

Saleth, R. M. and Dinar, A. 1999. *Water Challenge and Institutional Response (A Cross-Country Perspective).* World Bank Policy Working Paper No. 2045. Washington DC, The World Bank.

––––. 2004. *The Institutional Economics of Water: A Cross-Country Analysis of Institutions and Performance.* Cheltenham, UK/Washington DC, Edward Elgar/The World Bank.

Sandman, P. M. 2004. Acknowledging uncertainty. *The Synergist,* Nov., pp. 21–22, 41. A longer version of this article is available at http://www.psandman.com/col/uncertin.htm

Stakhiv, E.Z. and Pietrowsky, R. A. 2009. *Adapting to Climate Change in Water Resources and Water Service.* Alexandria, Va., US Army Corps of Engineers, Institute for Water Resources.

Stakhiv, E. Z. 2010. *Practical Approaches to Water Management under Climate Change Uncertainty.* Colorado Water Institute Information Series No. 109. Workshop in Nonstationarity, Hydrologic Frequency Analysis, and Water Management, 13–15 January 2010, Boulder, Colo.

Strachan, L. K. C., Ndengu, S. N., Mafanya, T., Coetzee, H., Wade, P. W., Msezane, N., Kwata, M. and Mengistu, H. 2008. *Regional Gold Mining Closure Strategy for the Central Rand Goldfield.* Council for Geosciences Report No. 2008-0174. Pretoria, South Africa, Department of Mineral Resources.

Sullivan, C. A. and Meigh, J. R. 2005. Targeting attention on local vulnerabilities using an integrated index approach: the example of the Climate Vulnerability Index. *Water Science and Technology,* Special Issue on Climate Change, Vol. 51, No. 5, pp. 69–78.

Timmerman, J. G., Koeppel, S., Bernardini, F. and Buntsma, J. J. 2010. Adaptation to climate change: challenges for transboundary water management. W.L. Filho (ed.) *The Economic, Social and Political Elements of Climate Change. Climate Change Management.* Berlin, Springer, pp. 523–41.

Thaler, R. H. and Johnson, E. J. 1990. Gambling with the house money and trying to break even: the effects of prior outcomes on risky choice. *Management Science,* Vol. 36, No. 6, pp. 643–60.

Turton, A. R. 2007. *Can we Solve Tomorrow's Problems with Yesterday's Experiences and Today's Science?* Des Midgley Memorial Lecture presented at the 13th SANCIAHS Symposium, 6 September 2007, Cape Town, South Africa.

––––. 2008. A South African perspective on a possible benefit-sharing approach for transboundary waters in the SADC region. *Water Alternatives,* Vol. 1, No. 2, pp. 180–200.

––––. 2010. The sustainability approach: managing water as a flux. J. Wilsenach (ed.) *The Sustainable Water Resource Handbook: South Africa: The Essential Guide.* Vol. 1., pp. 58–64. http://www.waterresource.co.za

Turton, A. R., Schultz, C., Buckle, H, Kgomongoe, M., Malungani, T. and Drackner, M. 2006. Gold, scorched earth and water: the hydropolitics of Johannesburg. *Water Resources Development,* Vol. 22, No. 2, pp. 313–335.

Turton, A. R., Hattingh, J., Claassen, M., Roux, D. J. and Ashton, P. J. 2007a. Towards a model for ecosystem governance: an integrated water resource management example. A. R. Turton, H. J. Hattingh, G. A. Maree, D. J. Roux, M. Claassen and W. F. Strydom (eds) *Governance as a Trialogue: Government–Society–Science in Transition.* Berlin, Springer-Verlag, pp. 1–28.

Turton, A. R., Godfrey, L. Julien, F. and Hattingh, H. 2007b. Unpacking groundwater governance through the lens of a trialogue: a Southern African case study. S. Ragone, N. Hernández-Mora, A. de la Hera, J. McKay and G. Bergkamp (eds) *The Global Importance of Groundwater in the 21st Century: Proceedings of the International Symposium on Groundwater Sustainability.* OH, National Groundwater Association Press, pp. 359–70.

UNECE (United Nations Economic Commission for Europe). 2006. *Strategies for Monitoring and Assessment of Transboundary Rivers, Lakes and Groundwaters.* ECE/MP.WAT/20. Geneva, UNECE. http://www.unece.org/env/water/publications/documents/StrategiesM&A.pdf

––––. 2007. *Recommendations on Payments for Ecosystem Services in Integrated Water Resources Management.* Convention on the Protection and Use of Transboundary Watercourses and International Lakes, Geneva, UNECE. http://www.unece.org/env/water/publications/documents/PES_Recommendations_web.pdf

––––. 2009. *Guidance on Water and Adaptation to Climate Change.* Convention on the Protection and Use of Transboundary Watercourses and International Lakes, Geneva. UNECE. http://www.unece.org/env/water/publications/documents/Guidance_water_climate.pdf

UNISDR, UNDP and IUCN. 2009. *Making Disaster Risk Reduction Gender-Sensitive: Policy and Practical Guidelines.* Geneva, UNISDR, UNDP and IUCN. http://www.preventionweb.net/files/9922_MakingDisasterRiskReductionGenderSe.pdf

US National Research Council. 2004. *Adaptive Management for Water Resources Planning.* Washington DC, The National Academies Press.

Van Tonder, D. and Coetzee, H. 2008. *Regional Mine Closure Strategy for the West Rand Goldfield.* Council for Geosciences Report No. 2008-0175. Pretoria, South Africa, Department of Minerals and Energy.

Van Wyk, E., Breen, C. M., Sherwill, T. and Magadlela, D. 2007. Challenges for the relationship between science and society: developing capacity for ecosystem governance in an emerging democracy. *Water Policy,* Vol. 9, No. 2, pp. 99–111.

Wettestad, J. 2008. *Interaction between EU Carbon Trading and International Institutions: Synergies or Disruptions?* EPIGOV Papers No. 34. Berlin, Ecologic – Institute for International and European Environmental Policy. http://ecologic.eu/projekte/epigov/documents/epigov_paper_34_wettestad.pdf

WWAP (World Water Assessment Programme). 2009. *World Water Development Report 3: Water in a Changing World.* Paris/London, UNESCO/Earthscan.

WWAP and UNSD (World Water Assessment Programme and United Nations Statistics Division). 2011. *Monitoring Framework for Water: The System of Environmental-Economic Accounts for Water (SEEA-Water) and the International Recommendations for Water Statistics (IRWS).* Perugia/New York, WWAP/UNSD.

Zalasiewicz, J., Williams, M., Smith, M., Barry, T. L., Coe, A.L., Bown,, P. R., Brenchley, P., Cantrill, D., Gale, A., Gibbard, P., Gregory, F. J., Houndslow, M. W., Kerr, A. C., Pearson, P., Knox, R., Powell, J., Waters, C., Marshall, J., Oates, M., Rawson, P. and Stone, P. 2008. Are we now living in the Anthropocene? *GSA Today,* Vol. 18, No. 2, pp. 4–8.

CHAPTER 12

Investment and financing in water for a more sustainable future

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Investment in water and sanitation is a vital concern for the many households that still lack these services. Water underpins all parts of a modern economy and its productive uses are also essential for poverty reduction. Water development is an integral part of a green economy: it is central to society's adjustment to climate change and is crucial to meeting future concerns for food security across the world.

Increased financing is necessary for all facets of water development, ranging from 'hard' infrastructure to equally important 'soft' items such as management; data collection, analysis and dissemination; regulation and other governance issues. The approach to financing propounded in this chapter is pragmatic and eclectic. It examines efforts to minimize the funding gap through internal efficiency and other measures; improve the generation of revenues from users, government budgets and official development assistance (ODA); and use these flows to leverage repayable finance such as bonds, loans and equity.

The current climate for international finance is difficult. It is therefore important to exploit all available risk-sharing tools. International financing institutions (IFIs) in particular have a key role to play.

12.1 Investing in water for sustainable development

A range of emerging factors are challenging enduring economic development stereotypes. These include the response to climate change, destabilizing fluctuations in commodity prices, concerns for food security, the increased role of public investment in infrastructure in response to the global financial crisis, and the desire of governments to limit their exposure to volatile international financial flows.

The current environmental imprint of infrastructure expansion is significant. It is therefore imperative that ways be found to design, operate and maintain systems that minimize negative environmental externalities at a lower cost than existing investments (Fay and Toman, 2010). Public policies should offer incentives for private sector decisions regarding investment and consumption that reflect the social benefits of environmental sustainability and the costs of various forms of environmental protection. At a global level there is a need to increase environmental research and development (R&D) and encourage the international transfer of cleaner technologies.

The *green economy agenda* is a response to these trends and seeks to reinforce and accelerate the progress of sustainable development.[1] It involves public policy, individual and collective business initiatives and private customer behaviour. The agenda has serious implications for water infrastructure. It increases pressure for more efficient use of resources and reductions in waste and greenhouse gas emissions, both of which aim to shift investment and consumption patterns towards alternatives that deplete less natural resources.

There are 11 key green economy sectors: agriculture, buildings, cities, energy, fisheries, forestry, manufacturing, tourism, transport, waste management and water.[2] The water development agenda overlaps with the green economy agenda in the following areas: pollution control, wastewater collection, treatment and reuse, successive uses of water, water use efficiency, energy efficiency in water and wastewater treatment, distribution and reuse, energy recovery, emission mitigation (capture of methane in wastewater treatment and irrigation), irrigation, and hydropower and management of natural water ecosystems (including wetlands).

A large percentage of these projects target several objectives simultaneously. This can often make financing such projects easier. Water development can thus gain from the economic and financial synergies that stem from the green economy. However, other actions justified by their 'greenness' may pose problems for water management unless they factor in and mitigate their potential impact on water. The promotion of biofuel technologies is an example of this. (For implications of biofuel developed for water resources management and use see Saulino, 2011.) Furthermore, to regard or compartmentalize water as a sector among others is too limiting, in spite of its presence as one of the 11 green economy sectors.

Investment in water infrastructure, in both its physical and natural assets, can be a driver of growth and the key to poverty reduction (Garrido-Lecca, 2010; UNEP, 2010). Although the recent global economic crisis set back investment in water in many countries (Winpenny et al., 2009), the impacts have been varied, and some governments have made determined efforts to compensate through counter-cyclical fiscal measures. Green investment in renewable energy, energy efficiency, more efficient use of materials, clean technology, waste mitigation, and sustainable use and restoration of ecosystems and biodiversity accounts for approximately 20% of the US$2 trillion of economic stimulus packages announced since 2008. Water is one of the beneficiaries of these programmes, although its full importance has not been recognized.

UNCTAD reports that 'there is considerable scope for developing economies in the [following] years and decades to gain from the opportunities that will emerge from the structural change towards renewable sources of energy, climate-friendly technologies, low-carbon equipment and appliances, and more sustainable modes of consumption' (UNCTAD, 2009, p. 168). Entry into these new markets could help developing and transition economies to combine climate change mitigation policies with faster growth and the creation of employment (UNEP, 2008). Developed countries dominate the global market for 'environmental goods', but some developing economies are building their market share based on their natural comparative advantages.

12.1.1 The Millennium Development Goals and sustainable development

Environmental goals cannot be achieved without development and efficiency. Poor people without adequate food, sustenance and water and sanitation will degrade their environment if they must do so to survive – even if it risks their long-term survival. Hence, sustainable development goals cannot be achieved and maintained without sound environmental management. Investment in programmes for poverty reduction is crucial for environmental policy, while investment in maintaining a healthy environment is vital for successful poverty reduction., However, investments remain seriously inadequate in many regions of the developing world to meet the Millennium Development Goals (MDGs).

The UN Millennium Project and the UN Millennium Ecosystem Assessment (MA, 2005; see Section 2.5) highlight the interdependencies between economic development and environmental management for poverty reduction and general well-being. The combination of poverty, vulnerability to drought and crop failure, lack of safe drinking water, and other environmentally related ills result in the deaths of millions of people each year. Over 1 billion people suffer from disease due to a lack of safe water, and are consequently less productive than they could be. The desperate situation of the poor therefore exacts a toll on the economy as well as on their environment and its ecosystem (Box 12.1). Lentini (2010) presents an overview for evaluation of the diverse benefits of water services in a typical developing country setting, especially for low income groups.

Alongside the UN's MDGs for ending poverty, eradicating hunger, achieving universal primary education, improving health, and restoring a healthy environment, the Millennium Ecosystem Assessment (MA) examines the consequences of ecosystem change for human well-being, and analyses options for conserving ecosystems while enhancing their contributions to human society. Environmental degradation is a major barrier to sustainable development and to the achievement of the MDGs. 'The MA examined 24 ecosystem services (the benefits people obtain from ecosystems) and found that productivity of only four had been enhanced over the last 50 years, whereas 15 (including capture fisheries, water purification, natural hazard regulation, and regional climate regulation) had been degraded. More than 70% of the 1.1 billion poor people surviving on less than US$1 per day live in rural areas, where they are directly dependent on ecosystem services.' (Sachs and Reid, p. 1002).

Investing in environmental assets and the management of those assets can help achieve national goals for relief from poverty, hunger and disease. Investments in improved agricultural practices to reduce water

BOX 12.1

Economics of access to improved drinking water and sanitation

Improving access to safe water and basic sanitation could have huge economic returns. World Bank studies in five South-East Asian countries estimate that around 2% of their combined GDPs are lost because of poor sanitation, and in the worst case (Cambodia) this figure rises to over 7% (World Bank, 2008). Economic benefits due to improvements in health include lower health system costs, fewer days lost at work or at school through illness or caring for an ill relative, and convenience time-savings (Hutton et al., 2007). The prevention of sanitation and water-related diseases could save approximately US$7 billion per year in health system costs, and the value of deaths averted, based on discounted future earnings, would add a further US$3.6 billion per year (Hutton et al., 2007). In fact, the World Health Organization (WHO) estimates that the overall economic benefits of halving the proportion of people without sustainable access to improved drinking water and sanitation, by 2015, would outweigh the investment cost by a ratio of 8:1 (Prüss-Üstün and Corvalán, 2006). Despite clear benefits to the development of individual countries' economies and health from increased access to sanitation and drinking water, 'many countries seem to allocate insufficient resources to meet the Millennium Development Goal target for sanitation and drinking water. When compared to other sectors (namely education and health sectors), sanitation and drinking water receive a relatively low priority for both official development assistance (ODA) and domestic allocations' (WHO/UN-Water, 2010, p. 2).

In fact, total aid for all aspects of water fell from 8% to 5% between 1997 and 2008 (WHO/UN-Water, 2010). Moreover, domestic and foreign aid are not necessarily well targeted to where need is greatest (e.g. the poorest and underserved populations). Less than half of the funding from external support agencies for water and sanitation goes to low income countries, and a small proportion of these funds is allocated to the provision of basic services, where it would have the greatest impact on achieving the MDG target (WHO/UN-Water, 2010). Stakeholders must continue to make the economic and development case for increased investment in sanitation and water. Furthermore, research must continue on the appropriate level of resources for sanitation and drinking water, compared to other sectors.

pollution can boost coastal fishing industry. Wetlands protection can help meet needs of rural communities while avoiding costs of expensive flood control infrastructure. (Sachs and Reid, p. 1002).

Conversely, reaching environmental goals requires progress in eradicating poverty. Coherent and bold poverty reduction strategies can ease environmental stresses by slowing population growth and enabling the poor to invest long term in their environment. Periodic environmental/ecosystem assessments would be helpful in this context.[3] 'A global network of respected ecologists, economists, and social scientists working to bring scientific knowledge to decision-makers and to the public can clarify the state of scientific knowledge, help to mobilize needed research', and counter any misinformation published by groups having special interests (Sachs and Reid, p. 1002).

12.2 Funding governance, institutional reform and management

To function properly and sustainably, all aspects of water resources management and water supply-related services must be fully funded. This not only includes the creation and maintenance of physical infrastructure, but also water resource management, environmental protection and pollution abatement measures, and less visible functions such as policy development, research, monitoring, administration, legislation enforcement, provision of public information, control of corruption and of conflicts of interest, and the involvement of public stakeholders (see Chapter 17).

BOX 12.2

Cost of adaptation to climate change for water

A World Bank study (see Chapter 24) has evaluated the impact of adapting the water sector to climate change in developing countries, over the period 2010–2050, based on a socio-economic baseline and two climate change scenarios, created by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia and the National Centre for Atmospheric Research (NCAR) in the United States of America.

The adaptive costs were defined in terms of hard options including building dams and dykes, and soft options such as the use of early warning systems, community preparedness programmes, watershed management, and urban and rural zoning.

The table below represents average annual water resource adaptations costs, combining riverine flood protection and industrial and municipal raw water supply. According to these estimates, measures to cope with the climate scenarios imply an annual increase in adaptation costs of US$13–17 billion for developing countries as a whole. This represents 3% of their GDPs. Africa is the worst affected region.

Average annual water resource adaptation costs (2010–2050) US$ billions (% GDP)

	Baseline*	CC (net costs)**	
Region		CSIRO**	NCAR
East Asia and Pacific	29.4 (0.06)	2.1 (0.00)	1.0 (0.00)
Europe and Central Asia	15.8 (0.03)	0.3 (0.00)	2.3 (0.00)
Latin America and Caribbean	13.4 (0.03)	3.2 (0.01)	5.5 (0.01)
Middle East and North America	11.9 (0.02)	0.1 (0.00)	-0.3 (0.00)
South Asia	34.9 (0.07)	4.0 (0.01)	-1.4 (0.00)
Sub-Saharan Africa	9.8 (0.02)	7.2 (0.01)	6.2 (0.01)
Total: developing country	115.1 (0.22)	16.9 (0.03)	13.3 (0.03)
Total: non-developing country	56.2 (0.11)	7.4 (0.01)	13.3 (0.01)

** The baseline year is 2050. 'Development baselines were crafted for each sector, essentially establishing a growth path in the absence of climate change that determines sector-level performance indicators … [using] a consistent set of GDP and population forecasts for 2010-50.' (World Bank 2010a, p. 2)*
*** Figures of 0.00 are positive amounts, rounded to the nearest decimal point; they do not imply zero amounts.*
Note: Discount rate = 0%; negative values refer to net benefits.
Source: World Bank (2010d; 2011). Table data from World Bank (2010e, table 5.4, p. 41).

Adequately funded water governance is essential to reduce uncertainty and manage risks. Generating data for policy-makers and managers (observations, analysis, modelling, scenario-building) helps to inform decision-makers and reduce uncertainty. Effective governance in areas such as environmental controls, groundwater monitoring and abstraction licensing, and monitoring and policing of pollution, can reduce the risk of over-exploitation of water resources and catastrophic surface water pollution and irreversible contamination of aquifers. Some of these governance functions can be self-financed through abstraction and pollution charges.

The same is true of regulation. Both public and private water agencies with operational functions should be subject to oversight from independent regulators with full and timely access to relevant information. Far-sighted service providers recognize the value of objective and transparent regulation in giving their activities the public scrutiny and sanction necessary to confer legitimacy and provide assurance against arbitrary actions for short-term political gain. Many regulators are funded by an earmarked tax on water bills (e.g. England and Wales, and Scotland) (see Chapter 25).

The third edition of the *World Water Development Report* (WWAP, 2009) highlighted the need to transcend the 'silo mentality' often found in water planning, and to take account of the wider implications of water decisions and the impact on water of decisions taken in other economic sectors. This is a central aim of integrated water resources management (IWRM). Among other development agencies, the World Bank aims to use its lending programmes to create capacity for IWRM as a way to overcome the institutional fragmentation which affects water. As part of this approach, the World Bank is working to incorporate the cross-cutting nature of water in its country programming, and integrate water interventions with projects in other sectors. In its water programmes, it intends to make focus on projects linking different components, hitherto funded separately, such as resource management, services, water quality and ecosystems (World Bank, 2010*b*).

Many water governance problems arise at the transboundary level, which is fraught with potential risks and conflicts. Capacity-building and management support for transboundary water institutions require proper funding. This is typically drawn from multilateral and bilateral agencies, local governments and other sources, usually in combination.

12.3 Funding for information

Chapter 6 of this report addresses the neglect and decline of national observation systems, which have caused a loss of vital hydrological data. Investment in the technology needed to upgrade countries' water and water-related information bases can result in good returns. As a result the World Bank and other agencies are targeting these systems for support (World Bank, 2010*b*). Such information is of vital national concern, but also constitutes a *regional and international public good*, albeit one which is 'seriously underfunded, and therefore under-provided' (Winpenny, 2009, p. 8). This is for three main reasons:

> Regional programmes and institutions involve co-operation between two or more neighbouring governments, often themselves poor, and which give transboundary issues a low priority compared to urgent national concerns. The problem is aggravated where neighbouring countries are at war with one another.[4]
>
> The attribution of benefits to the different partner countries is difficult, hence sharing costs is problematic, and hampers setting realistic budgets and funding modalities.[5]
>
> For such reasons both donors and recipients of Official Development Aid (ODA) may view regional public goods as less desirable objects than national programmes. Donors may also prefer supporting international, rather than regional, public goods out of self-interest, since they may perceive greater benefit accruing to themselves from actions of global concern. According to one estimate, only 3 to 4% of ODA goes to regional public goods, although such programmes can give high returns.

This problem is particularly acute in Africa: there are more than 60 transboundary rivers and international river basins cover 60% of the total area of the continent. Practically all African rivers cross several borders: the Nile crosses ten, the Niger nine, the Senegal four and the Zambezi eight. African water security will require the construction of regional and shared infrastructure on a large scale and the coordinated management of shared water infrastructure. Such an effort will require a greatly strengthened information base of regional climatic and hydrological data.

Better hydrological information about river regimes and groundwater reserves is essential for reducing uncertainty and anticipating climatic variability, which has had a heavy cost in many countries. In Kenya, losses from flooding from El Niño in 1997–1998 and drought from La Niña in 1998–2000 ranged from 10 to 16% of GDP during those years. Growth of GDP in Mozambique was reduced by 1% annually due to water shocks. In Zambia, hydrological variability is estimated to lower agricultural growth by 1% each year. Similarly, in Tanzania, the impact of the 2006 drought on agriculture caused losses equivalent to 1% of GDP (McKinsey, 2010). Reducing the damaging impact of this hydrological variability would have major benefits for the macroeconomy (AICD, 2010). Improved weather and flood forecasting is crucial to flood risk management, especially in reducing the impact of floods. Investment in weather forecasting and hydrometeorological services can be highly cost-beneficial.

In water resources management, for instance, there is a real need for better hydrological and meteorological information. The basic data should come from systems (including satellite observations) operated by national public and international agencies. However, in many cases agencies fail to collect or share the data. Private companies can also play a significant role in the generation, interpretation and application of such data for applied economic purposes. In France, a private company, Infoterra, provides satellite data for the analysis of farmland to anticipate the likely impact of climate change. In Germany, a private satellite operator, RapidEye, sells data to insurance companies marketing crop insurance to governments in countries at risk of drought and famine. Likewise, companies active in oil exploration and development offer unrivalled services for the prospection and exploitation of groundwater aquifers (Winpenny, 2010).

12.4 Funding in response to climate change and growing water scarcity

Projections reveal that the annual cost of climate change adaptation in developing countries in the industrial and municipal raw water supply sector would be between US$9.9–US$10.9 billion (net) and US$18.5–$19.3 billion (gross). Costs for riverine flood protection are projected at between US$3.5–$5.9 billion (net) and US$5.2–$7.0 billion (gross)[6] (Box 12.2).

Climate change will mainly be experienced through greater variability of temperatures and hydrological conditions. Adapting to *current* variability is an important first step in many cases. As the IPCC has observed, ‘many actions that facilitate adaptation to climate change are undertaken to deal with current extreme events’ (Adger et al., 2007, p. 719).

Greater variability around, and changes in, the climatic mean are likely to be compounded by greater *uncertainty* over the boundaries of variation, the possible appearance of new factors, and the presence of thresholds, irreversibilities and tipping points (see Chapter 2). Uncertainty has major implications for decision analysis and criteria (Box 12.3).

A common element of risk management, in view of the residual uncertainty about the impacts of climate change and other forces driving change, is the *no regret* criterion: a policy that would generate net social and/or economic benefit irrespective of what change occurs. Examples include demand management measures; improvements in the efficiency of water distribution; wastewater recycling; early warning systems for floods, droughts, and other extreme weather events; and risk-spreading through insurance schemes.

Although no-regret projects can be justified in financing terms, independent of the risks and uncertainties they face, there are many reasons why they may not happen: lack of project preparation, shortage of capital and credit, and a misalignment of social benefits with financial incentives for sponsors. These factors are seen in water demand-management programmes, for example, in cases where both household and industrial users seem reluctant to take up appliances and technologies that, on paper at least, promise rapid payback. No-regret projects may be attractive in theory, but may still require active promotion. Climate change impacts may lend them the extra benefits and impetus they need to make them a reality.

In comparison, projects justified solely on the basis of expected climate change would only be justifiable if the predictions of climatic and hydrological models proved accurate. Such projects include construction of new storage and supply infrastructure, retrofitting of existing structures, altering operational protocols, and developing new water sources and water transfers. Such climate-justified projects and policies have to be planned and implemented against the backdrop of an uncertain future. The key criteria for these projects are resilience, robustness, flexibility and *intelligence* (the ability to provide services or management over a range of possible conditions). Depending on circumstances, some of these projects may have benefits outside of a climate change scenario. As the IPCC observes, 'adaptation measures are seldom undertaken in response to climate change alone' (Adger et al., 2007, p. 719).

Ensuring the capacity to cope with the greater variability and uncertainty caused by climate change and other change forces (see Chapters 1 and 9) constitute a broad challenge for water infrastructure. The measures required will pose severe tests for governments, public agencies and international research institutes. Their efforts will need to be supplemented by the actions of private, non-governmental bodies of all kinds, who can add value though extra resources, different ways of working, new approaches and innovative products. Adaptation and mitigation projects implemented by public agencies can draw on a range of development funds, including new adaptation funds created for this specific purpose. There are currently over 20 specialized climate change funds accessible to public agencies.[7] Leaving aside those funds specializing in forestry or energy, around a dozen funds are available for adaptation for water, amongst other sectors. Of particular relevance is the funding provided by the Pilot Program for Climate Resilience (PPCR), sponsored by the World Bank and other major IFIs:

> The pilot programs and projects implemented under the PPCR are country-led, and build on National Adaptation Programs of Action (NAPA) and other relevant country studies and strategies. They are strategically aligned with other donor-funded activities to provide financing for projects that will produce experience and knowledge useful to designing scale-up adaptation measures. (CIF, 2011)

Specifically, funding is available through PPCR for technical assistance to assist developing countries in 'integrating climate resilience considerations into national development planning' (CIF, 2011).

BOX 12.3

Implications of climate change uncertainty for decision-making

Greater variability and fundamental uncertainty would have profound implications for decisions about water infrastructure, which typically has a long physical life. These implications are at various levels, and of different kinds:
The *climate risk* of such infrastructure should be assessed, at a sector and/or project level.

Traditional ways of dealing with risk in *cost–benefit analysis* need to be fully exploited: these methods include sensitivity analysis, switching values, and risk-benefit analysis.

Decision rules should be used that take into account the *risk preferences* of the agency concerned (minimax, maximin, minimum regret) (Ben Tal et al., 2009).

These traditional aids to decision-making under uncertainty and risk need to be complemented by the use of *scenario building,* which constructs a series of plausible futures, which could not necessarily have been predicted by extrapolation from current trends. Projects which stand up well on different scenarios are considered to be *robust* (World Bank, 2010*a*).

Project design needs to allow for greater climatic variability, and be resilient in dealing with events that cannot be foreseen as yet. The initial cost of building in resilience (e.g. greater storage, which may not be needed; or forfeiting current economies of scale in favour of greater freedom of manoeuvre in future) could be regarded as an insurance premium to avoid future losses in the CC scenario.

Source: Reproduced from Winpenny (2010, pp. 1–2).
Note: Sensitivity analysis measures the impact on a project's rate of return of a change in a specific variable. Switching values are the change in a specific variable required to reduce the rate of return to zero. Risk-benefit analysis compares the risk of action (= its cost) with the benefit of action (= avoided loss).
Minimax = minimizing the maximum expected loss; maximin = maximizing the minimum likely outcome; minimum regret = minimizing the difference between the worst possible outcome and others.

There is a risk that these climate change funds might add to the administrative burdens placed on recipients (Porter et al., 2008). Such funds can be useful sources of money for pilot projects (e.g. the PPCR), but at a country level there is a strong case for 'mainstreaming' adaptation as much as possible, rather than consigning it to a marginal part of the public investment programme, requiring its own procedures and criteria.

Much of the adaptation and mitigation effort, however, will fall to private companies, farmers and households, as well as subsovereign agencies that cannot access these development funds. For them, commercial financial sources are critical. Microfinance is particularly suitable for financing the improvement of irrigation efficiency for small farmers. Certain forms of contract can also be funded by quasi-equity, in which rewards depend on the successful achievement of project aims, for example, performance-related contracts for water leakage reduction.

"Microfinance is particularly suitable for financing the improvement of irrigation efficiency for small farmers."

12.5 Funding diversification and demand management

Diversifying the sources of water by increasing the use of technologies, such as desalination and reclaimed water and promoting self-supply by users (farmers, households and companies) can reduce and distribute risk, compared with relying on a few sources that are dependent on the same hydrological system. Some of these are easier to finance from conventional means than others. Desalination plants and certain projects for the use of reclaimed water, which entail sizeable investment in wastewater treatment plants (WWTPs), lend themselves to public sector or stand-alone commercial ventures funded from equity and commercial finance – typically under a form of concession contract. In Mexico, the Atotonilco WWTP re-uses treated urban wastewater in irrigation. Under the terms of a recent contract, bids were invited under a build-operate-transfer (BOT) structure, with 49% of costs coming from the National Infrastructure Fund and the remainder from the private concessionaire. The Matahuala and El Morro WWTPs have similar aims and financing structures: design-build-operate-transfer (DBOT) and BOT, respectively (GWI, 2009, pp. 51–2).

Dealing with future water deficits will also require action on the demand side. Demand management needs a different approach to financing. In South Africa, current trajectories and policies produce urban, agricultural and industrial growth projections to 2030 incompatible with the country's water endowment. In the base case scenario, South Africa faces a gap between projected 2030 demand and current supply equivalent to 17% of demand. Moreover, the impact of climate change might increase the size of this gap. Competition for limited water supplies will intensify in each of the basins feeding the largest cities (Johannesburg, Pretoria, Durban and Cape Town). Household demand is expected to increase as a result of income growth and improved service coverage. The current planning scenario for the Vaal system (Johannesburg, Pretoria and surrounding areas) assumes that demand management will reduce demand increases under a business-as-usual (BAU) scenario by 15% (although that is not yet happening), which will generate substantial investment burdens. Agriculture is not seen as a major growth sector, although its water allocation may need to decrease, implying greater efficiency in its use. Meanwhile, industry, power generation, mining and agriculture – the sectors that will drive the income growth – are all water-intensive.

Closing the projected supply-demand gap for water in 2030 and thereby enabling South Africa's growth potential to be realized can be achieved with a portfolio of different measures: supply-side transfer schemes, new dams and modifications to existing structures, re-engineering of existing irrigation schemes to increase water efficiency, and better use of water in mining and industrial companies. In short, a balance of supply-side and demand management measures are needed. Much of the cost of demand management falls on consumers – households, farmers and industries – and is financed largely by them, though governments can help with subsidies and tax breaks (McKinsey, 2010).

12.6 Generating finance for water infrastructure and services

All countries at every level of development face heavy costs in creating a water infrastructure that is 'fit for purpose', which can address the growing challenges and risks identified throughout this report.

According to a recent World Bank Study (2010*c*), the global financial crisis has negatively impacted progress towards fulfilling the MDGs. The crisis will also potentially magnify the already large investment needs. Using three macroeconomic scenarios to illustrate the risks involved, the report reveals that serious global shortfalls are looming in water development indicators. According to one projection for 2015, 100 million more people will lose access to safe drinking water. A rethinking in financing strategies is therefore required to ensure that improvement in public expenditure efficiency results in additional resources.

The African Infrastructure Country Diagnostic (AICD, 2010) determines the investment needs in infrastructure in sub-Saharan Africa. This tool assists policy-makers to set priorities for investment in all infrastructure sectors and provides a baseline for monitoring progress. The AICD estimates that US$22 billion per year (approximately 3.3% of Africa's GDP) is the amount required to attain the MDGs in water and sanitation. These estimates, based on minimum acceptable asset standards, include an annual capital expenditure of US$15 billion and operating expenditures of around US$7 million. These figures do not include the cost of investment in hydropower or irrigation. Similar estimates for Latin America and the Caribbean are available in an IDB study (2010) 'Drinking Water, Sanitation, and the Millennium Development Goals in Latin America and the Caribbean'.

A pragmatic and eclectic approach is required to raise the sums needed. The first step should be to squeeze the financing requirements to a minimum through improvements in efficiency, better collections of revenues due, and adjustments to service levels and technological solutions (AICD, 2010). The second step is to improve the rate of *sustainable cost recovery* by raising tariff revenues, budgetary allocations due from governments and ODA. In this context, the willingness to pay of water users may well be greater than the willingness to charge of politicians. The third step is to use these revenues to attract repayable sources of funds, using available devices for the reduction, mitigation and sharing of water financing risks (Winpenny, 2003; OECD, 2010a among others).

Raising commercial finance for water has become more difficult due to the global financial situation since 2007, which

> has discouraged new private interest in water infrastructure projects, and has also unsettled partners in existing private public partnership (PPP) ventures. Earlier in 2009 the IFC reported that US$200 billion of PSP projects had been postponed or had become 'at risk', 15–20% of which were in water supply and sanitation. The financial climate affected both the supply of risk capital (e.g. equity) and loan capital to finance these concession deals, since liquidity has become scarce, and the problems of international banks have had repercussions on local banks too. Many innovative deals, developed with technical assistance and risk-sharing from donor agencies, are at risk. (Winpenny et al., 2009, p. 18)

The Private Participation in Infrastructure (PPI) database, maintained by the World Bank and the Public-Private Infrastructure Advisory Facility, reported that in 2009 the number of water projects reaching financial or contractual closure had declined by 46% compared with 2008, and that annual investment commitments had fallen by 31% over the same period. In 2009, 35 water projects with private participation were implemented in seven low or middle income countries, involving investment of around US$2 billion. However, three countries (Algeria, China and Jordan) accounted for most of this activity (see Chapter 24).

> Many projects that were close to financial closure when the crisis broke have survived by switching their sources of funding to local public banks or agencies. Even when the financial crisis abates financing terms for PSP deals in water and other sectors are likely to remain harsh, and will call for more 'conservative' project financing structures (i.e. more equity, less debt, more risk mitigation) … These developments are occurring against (and reinforce) a gathering trend towards more selectivity in the choice of markets and type of project by the handful of western multinationals that remain in the market for new international water concessions. (Winpenny et al., 2009, p. 18)

However, these multinationals are increasingly joined by more recent market entrants from Latin America, the Middle East, Southeast and East Asia and elsewhere (Winpenny, 2006).

Public-private partnerships (PPPs) in urban water utilities have had a mixed record in developing countries, with relative success in some (mainly in Chile) and problems in others (e.g. Argentina and Bolivia) (Jouravlev, 2004; Ducci, 2007; Lentini, 2011) and in increasing efficiency than in directly bringing new finance (Marin, 2009). This is particularly relevant as many urban water transmission and distribution systems are highly inefficient in their use of water and energy (AICD, 2010; Kingdom et al., 2006). Improved cost control and better cash flow in utilities will indirectly increase their ability to raise their own finance. This also has implications for energy costs. Water is a large and generally inefficient consumer of energy. This constitutes a sizeable percentage of water delivery cost, even at the subeconomic electricity prices that often apply. The use of more marginal sources as water becomes scarcer will increase the energy requirement for sourcing and treatment (GWI, 2009).

Another potential source of finance would be improving the rate of collection of water bills. In Africa, under-collection is valued at US$0.5 billion annually. Improving the collection rate is an obvious way of increasing water revenues without raising tariffs. Although the better performing water utilities in Africa normally manage collection rates of 80% or more (Mehta et al., 2009), persistent non-payment, especially by public departments and agencies, leaves a big hole in the accounts of water authorities normally be expected to be self-sufficient.

International financial events since 2007 have consolidated the position of national and international public agencies as important sources of finance for water infrastructure. Though many national governments are constrained by their fiscal position, others have benefited from strong commodity prices and have used their fiscal resources to invest in infrastructure, including water (Winpenny et al., 2009). Although the share of water in total ODA has declined since the mid-1990s, the *absolute volume* of ODA has started to rise (Box 12.4). In 2007–2008, the bilateral annual aid commitments of DAC countries to water and sanitation rose to US$5.3 billion. Including concessional outflows of multilateral agencies the total ODA for water and sanitation for that period was US$7.2 billion (OECD-DAC, 2010), compared with US$5.6 billion in 2006.

In addition to ODA, which in the case of water and sanitation is evenly split between grants and soft loans (OECD-DAC, 2010), public international development banks (World Bank, regional development banks, European Investment Bank) offering loans on attractive terms have regained some market share for infrastructure finance during the recent financial crisis, taking advantage of the absence of commercial lenders (e.g. World Bank, 2010*b*). The Asian and Middle Eastern sovereign wealth funds and publicly sponsored companies are an additional and increasingly important source of money for the development of natural resources and infrastructure (ICA, 2007). The abovementioned public sources of grant and commercial finance are likely to remain important funders of big water infrastructure projects, especially in Africa.

Nearly all the revenues generated by water accrue in local currency (with the exception of transboundary water and power sales, and the indirect benefit to foreign exchange through exports of produce).

BOX 12.4

Increasing aid to water and sanitation: 2002-2008

Aid to water and sanitation has been rising sharply since the 2002-2003 reporting period, from total average commitments of US$ 3.3 billion to US$7.2 billion in 2007-2008 (last reported period and includes DAC member countries' contributions and multilateral agencies' concessional flows). Among DAC members the largest donors for this last reported period were Japan (on average US$1.9 billion per year), Germany (US$771 million) and the USA (US$644 million). Over the period 2003–2008 aid to water and sanitation primarily targeted regions most in need of improved access to water and sanitation: sub-Saharan Africa received 29% of total aid to the sector, and South and Central Asia 18%. Poorest countries classified as 'low income' received 43% of total aid to the sector, two-thirds of which was in the form of grants. Projects for the category defined as 'large systems' are predominant and accounted for 57% of total contributions to the water and sanitation sector in 2007-08. 68% of total ODA for large systems was in the form of loans, and loans also represented 33% of the financing for river development. By contrast, donors relied almost exclusively on ODA grants (90% of total) to finance basic drinking water and sanitation. Grants were also predominant in the subsectors of water resources policy and administrative management, water resources protection and education and training.

Source: OECD (2010b).

This introduces a foreign exchange risk into loans and equity capital raised externally, even on favourable financing terms (e.g. from IFIs). Devaluation has been catastrophic for some high-profile international water concessions[8] needing to service their debt in foreign currency, and is a serious potential risk for all water projects and providers, both private and public. Hedging against devaluation risk is not a practical proposition. The more sustainable long-term solution is to generate more internal revenues from tariffs, and to rely as much as possible on local financial and capital markets, as suggested by experiences in Chile and Brazil (Jouravlev, 2004; Lentini, 2011). A number of donors and IFIs offer risk-sharing products (see Section 12.7) to encourage the growth of local currency finance for water and other infrastructure.[9]

12.7 Mitigating financial and political risks

Many local water utilities are funded with revenues from users or public budgets insufficient to exceed their day-to-day operating costs. As a result, they lack adequate cash flow to borrow money. Such utilities cannot fund long-term investments if they do not receive grant subsidies. However, many that might have adequate cash flows remain unable to finance investments through borrowings, either because lenders perceive them as an unacceptable risk or because their potential rating results in loans with short terms and high interest rates.

Financial markets have a variety of ways of dealing with the risks for lenders and investors discussed in this report. Insurance and guarantees can 'cover political, contractual, regulatory and credit risk from both multilateral and bilateral development agencies. These guarantees have a *development* motive, as opposed to export credit and investment insurance, limited to firms domiciled in the country offering the guarantee, which has a *commercial* aim. There is also a large and active *private* market offering insurance' against political, contractual and credit risks. In addition to these *external* guarantees, *sovereign* guarantees are those 'offered by *national* governments to their own citizens, companies or subsovereign bodies when they borrow or attract direct investment. Certain other instruments have a *quasi-guarantee* status, such as the 'umbrellas of comfort' which IFIs and other agencies erect over other lenders and investors through participations ('B loans') and Municipal Support Agreements' (Winpenny, 2005).[10]

Political risks affect not only lenders and investors. They also impact water utilities which depend on political decisions for setting rules and objectives, fixing tariffs or allocating subsidies. Water utilities can only finance investment through borrowings if their revenues are sufficiently predictable. Many investments are delayed by a failure – often for political reasons – to adjust tariffs to changes in economic conditions. Public subsidies that cannot be anticipated cannot form the basis for borrowing.

Guarantees work in various ways: mitigating specific risks which are the critical sticking points on a project; enhancing securities (e.g. bonds) to take them over a critical threshold of creditworthiness; improving the terms on which borrowers and project sponsors can get access to loans and investment; and giving lenders and investors exposure to previously unfamiliar markets and products (Winpenny, 2005; Matsukawa and Habeck, 2007; OECD, 2010*a*).

Guarantees for investment in water services projects have not been widely adopted, compared with other sectors. Of 124 guarantees issued since 2001 by IFIs, only four were issued for water supply and sanitation projects. This outcome is a mixture of governance and incentive factors affecting both the supply of funds from the originating agencies and the attitudes and practices of borrowers and host governments. Guarantees can mitigate specific risks, but cannot offset other negative project fundamentals often present in water services (Winpenny, 2005; Matsukawa and Habeck, 2007; OECD, 2010*a*). However, they can form a crucial feature of complex strategic infrastructure finance packages, such as the Nam Theun Hydro Project in Lao PDR. The World Bank's Multilateral Investment Guarantee Agency (MIGA) investment guarantees against political and specific regulatory risk have also proved helpful to the financing of water projects (World Bank, 2010*b*).

Pooling mechanisms are another device to reduce perceived risks. Some countries have developed national revolving funds, following the well-established model used in the United States of America. Another example is the decision taken by a group of communities in Colombia in 2010 to form a trust, which issued a US$92 million peso-denominated bond to domestic investors on the Colombian stock exchange. The deal, done under the auspices of Colombia Infrastructure Group LLC, allowed small and medium-sized municipalities access to long-dated funds at competitive rates, with the express purpose of funding local water and wastewater projects (GWI, 2010).

All potential financiers are concerned with managing the reputational risk entailed by certain types of infrastructure projects. The World Bank terms such projects 'high risk-high reward'. The typical IFI response is to develop an extensive set of processes and operational policies to ensure that high risk-high reward (HRHR) projects risks are appropriately addressed and mitigated (World Bank, 2010*b*).

As a general principle, the risk of financial default can be managed by tailoring financial terms to the risk profile and expected cash flow of the project concerned. For large and complex projects it is becoming common to blend different types of finance (commercial loans, concessionary loans, grants, equity) to achieve an acceptable overall mix. A number of international platforms now exist (e.g. the EU-Africa Infrastructure Trust Fund and the EU Neighbourhood Investment Facility) to fund major infrastructure projects on terms appropriate to borrowers' repayment ability and the specific risks in each case.

Another risk management approach is to allow the financial terms to adjust to the outcome of a project. *Convertible loans* can be converted into equity when cash flow would otherwise cause debt-servicing problems. The interest rate on some loans is indexed to the price of the good or service provided by the project, where this is outside the control of the sponsor.

Another outcome-oriented financial device is *output-based aid* (OBA), which is only released to the sponsor when a project is completed and up and running. The sponsor has the assurance that the grant will be forthcoming in due course, enabling commercial finance to be raised, but the clients (local government and international agencies) have the assurance that their funds will not be wasted. There are currently 31 projects with OBA from the World Bank in water supply and sanitation (World Bank, 2010*b*).

Among other innovative funding methods to cope with the heightened risks of water management are index insurance and weather derivatives for farmers (Winpenny, 2010). Other risk mitigation methods include options on water stored in reservoirs and 'contract options' bought by urban water authorities for the use of farmers' water rights in times of drought. All these methods provide insurance against water variability, while avoiding the heavy costs of new infrastructure.

> "A precondition of adequate financing for water is a full appreciation of the social and economic purposes that it serves."

A recent review of innovative finance for water notes that commercial funding of all types has suffered from global financial turmoil. Instruments, such as guarantees have been underutilized, and the credibility of complex structured financial products has been weakened. The long-term flow of commercial, including private, finance to water depends on reforms to its governance and operation, and novel forms of finance will remain limited by this constraint. However, there is considerable scope for blending public grant and concessional funds with commercial sources, as noted in the examples above (OECD, 2010*a*).

Conclusion

Water, in its various forms, will need to attract much more finance than it currently receives if it is to overcome its current under-funding, support the future expansion of food production, supply the needs of growing populations including those in the post-2015 MDG targets, and continue performing all the other services it provides to a modern, growing economy. The new impetus to create a green economy offers opportunities, as well as challenges, for the management of water. Climate change sets its own agenda, in addition to and partially overlapping with the above, involving the mitigation of greenhouse gas (GHG) emissions and the adaptation of water infrastructure and services. Water is also central to disaster preparedness, which is likely to increase in importance for any future climate scenario.

One basic reason why water does not receive sufficient funding is that its scope is often viewed too narrowly, whereas in reality it underpins a wide range of economic sectors, all of which would be threatened by water scarcity, pollution or pressures from the other drivers described in this report. Hence, a precondition of adequate financing for water is a full appreciation of the social and economic purposes that it serves.

Even with this, however, the financial climate for water will remain challenging and will call for a pragmatic and eclectic approach to funding. This chapter outlines such an approach, involving a mixture of efficiency measures, review of standards and technological options, improved rates of collection, better cost recovery from water users, more predictable government budgetary allocations and ODA, and the intelligent use of such basic revenues to attract repayable funding sources using the array of risk-sharing devices now available.

Notes

1 A green economy is 'an economy that results in improved human well-being and reduced inequalities over the long term, while not exposing future generations to significant environmental risks and ecological scarcities' (UNEP, 2010, p. 4).

2 For more information see http://www.unep.org/GreenEconomy/Portals/93/documents/Full_GER_screen.pdf

3 Possibly modelled on the UN Millennium Assessment reports, the GEO series, or the OECD's Environmental Outlooks.

4 Control of the desert locust in Sahelian countries has been severely hampered by the decline of regional information and monitoring systems, due in part to civil unrest and armed conflict endemic in border regions in these countries.

5 Birdsall (2006) cites the Southern Africa Power Pool, the Baltic Sea clean up, the control of onchocerciasis in the Sahel, and the control of Chagas disease in Latin America.

6 Gross costs include all costs incurred by adaptation to climate change. Net costs allow for (i.e. deduct from gross) any negative costs (i.e. cost savings) that may arise from climate change. The method used in this study nets out positive and negative cost items for each country, but not across countries within a region (World Bank, 2010c: pp. 3, 54, and elsewhere).

7 For more information see http://www.climatefundsupdate.org/listing

8 Buenos Aires, the original West Manila concession, and Jakarta. The West Manila concession inherited earlier debt owed to the World Bank and Asian Development Bank.

9 For example, the US Development Credit Agency, the Agence Française de Développement, and the GUARANTCO scheme of DFID, SIDA and others.

10 A form of lending used by the European Bank for Reconstruction and Development in which loans to a subsovereign body, such as a local water utility, are made under a formal understanding that the responsible municipality will do everything in its power to enable the utility to continue servicing the debt.

References

Adger, W. N., Agrawala, S., Mirza, M. M. Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, P., Smit, B. and Takahashi, K. 2007. Assessment of adaptation practices, options, constraints and capacity. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (eds) *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK, Cambridge University Press, pp. 717–43.

AICD (Africa Infrastructure Country Diagnostic). 2010. *Africa's Infrastructure: A Time for Transformation.* Washington DC, The World Bank/Agence Française de Développement.

Ben-Tal, A., L. El Ghaoui, L. and A. Nemirovski, A. 2009. *Robust Optimization.* New Jersey, NY, Princeton University Press.

Birdsall, N. 2006. Overcoming coordination and attribution problems: meeting the challenge of underfunded regionalism. I. Kaul and P. Conceicao (eds) *The New Public Finance: Responding to Global Challenges.* Oxford, Oxford University Press.

CIF (Climate Investment Funds). 2011. Pilot Program for Pilot Resilience. Washington DC, CIF. http://www.climateinvestmentfunds.org/cif/ppcr

Ducci, J. 2007. *Salida de operadores privados internacionales de agua en América Latina.* Washington DC, Inter-American Development Bank (IDB). http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=957044

Fay, M. and Toman, M. 2010. Infrastructure and sustainable development. *Post-Crisis Growth and Development.* Washington DC, International Bank for Reconstruction and Development/The World Bank, pp. 329–82.

Garrido-Lecca, H. 2010. *Inversión en agua y saneamiento como respuesta a la exclusión en el Perú: gestación, puesta en marcha y lecciones del Programa Agua para Todos (PAPT).* LC/W.313. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/4/41044/lcw313e.pdf

GWI (Global Water Intelligence). 2009. *Global Water Intelligence.* August, pp. 51–2.

––––. 2010. *Global Water Intelligence.* Briefing, 9 December.

Hutton, G., Haller, L. and Bartram, J. 2007. *Economic and Health Effects of Increasing Coverage of Low-cost Household Drinking-Water Supply and Sanitation Interventions to Countries Off-Track to Meet MDG Target 10.* Geneva, World Health Organization (WHO).

ICA (Infrastructure Consortium for Africa). 2007. Annual Report. Tunis Belvedere, Tunis, ICA.

IDB (Inter-American Development Bank). 2010. *Drinking Water, Sanitation, and the Millennium Development Goals in Latin America and the Caribbean.* Washington DC, IDB Water and Sanitation Initiative. http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=35468495

Jouravlev, A. 2004. *Drinking Water Supply and Sanitation Services on the Threshold of the XXI Century.* LC/L.2169-P. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.eclac.cl/publicaciones/xml/9/19539/lcl2169i.pdf

Kingdom, B., Liemberger, R. and Marin, P. 2006. *The Challenge of Reducing Non-revenue Water (NRW) in Developing Countries – How the Private Sector Can Help: A Look at Performance-based Service Contracting.* Water Supply and Sanitation Board Discussion Series, No. 8. Washington DC, International Bank for Reconstruction/The World Bank.

Lentini, E. 2010. *Servicios de agua potable y saneamiento en Guatemala: beneficios potenciales y determinantes de éxito.* LC/W.335. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/0/41140/lcw335e.pdf

Lentini, E. 2011. *Servicios de agua potable y saneamiento: lecciones de experiencias relevantes.* LC/W.392. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC). http://www.cepal.org/publicaciones/xml/9/43139/Lcw392e.pdf

MA (UN Millennium Ecosystem Assessment). 2005. *Living Beyond our Means. Natural Assets and Human Well-being.* Statement from the Board. March 2005

Marin, P. 2009. *Public-private Partnerships for Urban Water Utilities: A Review of Experiences in Developing Countries.* Washington DC, International Bank for Reconstruction/The World Bank.

Matsukawa, T. and Habeck, O. 2007. *Review of Risk Mitigation Instruments for Infrastructure Financing and Recent Trends and Developments.* Washington DC, International Bank for Reconstruction/The World Bank.

McKinsey & Company. 2010. *Charting our Water Future: Economic Frameworks to Inform Decision-making.* 2030 Water Resources Group. http://www.2030waterresourcesgroup.com/water_full/

Mehta, M., Cardone, R. and Fugelsnes, T. 2009. *How Can Reforming African Water Utilities Tap Local Financial Markets?* Insights and recommendations from a practitioners' workshop in Pretoria, South Africa, July 2007 (Revised in 2009). Washington DC/Tunis, Tunisia, Water and Sanitation Programme (WSP)/Public-Private Infrastructure Advisory Facility (PPIAF)/African Development Bank (AfDB).

OECD (Organisation for Economic Co-operation and Development). 2010*a*. *Innovative Financing Mechanisms for the Water Sector.* Paris, OECD.

––––. 2010*b*. *Financing Water and Sanitation in Developing Countries: The Contribution of External Aid.* Paris, OECD.

OECD-DAC (OECD Development Assistance Committee). 2010. *Focus on Aid to Water and Sanitation.* Paris, OECD. http://www.oecd.org/dac/stats/water.

Porter, G., Bird, N., Kaur, N. and Peskett, L. 2008. *New Finance for Climate Change and the Environment.* Washington DC, World Wide Fund for Nature (WWF)/Heinrich Böll Foundation.

Prüss-Üstün, A. and Corvalán, C. 2006. *Preventing Disease through Healthy Environments: Towards an Estimate of the Environmental Burden of Disease.* Geneva, World Health Organization (WHO).

Sachs, J. D. and Reid, W. V. Investments toward sustainable development. Science, Vol. 312, p. 1002. http://www.unmillenniumproject.org/documents/ScienceMag_19-05-06.pdf

Saulino, F. 2011. Implicaciones del desarrollo de los biocombustibles para la gestión y el aprovechamiento del agua. LC/W.445. Santiago, United Nations Economic Commission for Latin America and the Caribbean (ECLAC).

UNCTAD (United Nations Conference on Trade and Development). 2009. *UNCTAD Trade And Development Report 2009.* Geneva, UNCTAD. http://www.unctad.org/en/docs/tdr2009_en.pdf

UNEP (United Nations Environment Programme). 2008. *Green Jobs: Towards Decent Work in a Sustainable, Low-carbon World.* Nairobi, UNEP.

––––. 2010: *Green Economy Report: A Preview.* Nairobi, UNEP.

WHO (World Health Organization)/UN-Water. 2010. GLAAS 2010. *UN-Water Global Annual Assessment of Sanitation and Drinking Water: Targeting Resources for Better Results.* Geneva, WHO/UN-Water.

Winpenny, J. 2003. *Camdessus Report. Financing Water for All: Report of the World Panel on Financing Water Infrastructure.* Stockholm/Marseilles, France, Global Water Partnership (GWP)/World Water Council (WWC).

––––. 2005. *Guaranteeing Development? The Impact of Financial Guarantees.* Paris, OECD.

––––. 2006. *Opportunities and Challenges Arising from the Increasing Use of New Private Water Operators in Developing and Emerging Economies.* Background paper for OECD Global Forum on Sustainable Development, Paris.

––––. 2009. *Investing in Information, Knowledge and Monitoring.* UN WWAP, Side Publications Series. Scientific Paper. Paris, UNESCO Publishing.

Winpenny, J., Bullock, A., Granit, J. and Löfgren, R. 2009. *The Global Financial and Economic Crisis and the Water Sector.* Stockholm, Stockholm International Water Institute (SIWI).

Winpenny, J. T. 2010. *Private Providers of Climate Change Services: The Role and Scope for the Private Sector in the Provision of Non-financial Climate Change-related Services Relevant to Water Infrastructure.* Water Working Notes No. 26. Washington DC, The World Bank.

World Bank. 2008. *Economic Impact of Sanitation in Indonesia: A Five-country Study Conducted in Cambodia, Indonesia, Lao PDR, the Philippines, and Vietnam Under the Economics of Sanitation Initiative.* Water and Sanitation Program. Washington DC, The World Bank.

World Bank. 2010*a*. *The Cost to Developing Countries of Adapting to Climate Change. New Methods and Estimates.* The Global Report of the Economics of Adaptation to Climate Change Study. Consultation Draft. Washington DC, The World Bank.

––––. 2010*b*. *Sustaining Water for All in a Changing Climate: World Bank Group Implementation Progress Report of the Water Resources Sector Strategy.* Washington DC, International Bank for Reconstruction/The World Bank.

––––. 2010*c*. *Global Monitoring Report 2010: The MDGs After the Crisis.* Washington DC, The World Bank.

––––. 2010*d*. *The Economics of Adaptation to Climate Change: New Methods and Estimates.* Washington DC, International Bank for Reconstruction/The World Bank.

––––. 2010*e*. The Economics of Adaptation to Climate Change. Background Papers: Costs of Adaptation Related to Industrial and Municipal Water Supply and Riverine Flood Protection (P. J. Ward, P. Pauw, L. M. Brander, Jeroen, C. J. H. Aerts and K. M. Strzepek) Discussion Paper No. 6. Washington DC, The World Bank. http://siteresources.worldbank.org/EXTCC/Resources/407863-1229101582229/DCCDP_6Riverine.pdf

WWAP (World Water Assessment Programme). 2009. *United Nations World Water Development Report 3: Water in a Changing World.* Paris/London: UNESCO Publishing/Earthscan.

CHAPTER 13

Responses to risk and uncertainty from a water management perspective

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Increasing uncertainty concerning the availability and quality of water resources and their use poses unique challenges for decision-makers (Shaw and Woodward, 2010). Rapid, sometimes unforeseeable changes in external pressures and drivers are the cause of these new and increased uncertainties and associated risks (see Chapters 8 and 9). Managing these risks and taking advantage of any opportunities that arise calls for new kinds of action involving all stakeholders, many of whom have not as yet considered how their decisions and actions affect water.

Water managers employ differing approaches to address the risks and uncertainties surrounding water resources (Chapter 11), relying on the 'rules' set in place by their local and national institutions (Chapters 5 and 11). They have tools and options at their disposal to facilitate the transformation of traditional static planning and management approaches into more adaptive and flexible practices that can increase the resilience of water systems. These include informing the people who make decisions affecting water of the potential benefits and costs of altering allocations to different uses, and the trade-offs among various performance criteria that may need to be made. Although water managers play a significant part in this process, expertise is also required from the social and economic sectors (and from the ultimate beneficiaries).

Water managers operate in differing contexts: some function and adapt to circumstances where governments anticipate water scarcity and variability and adopt precautionary policy instruments; others may have to operate in a context where governments prefer to maintain the status quo in policy development despite changes affecting water resources. Despite the differing contexts, water managers need to review their risk assessment and management practices. Moreover, they need to raise awareness among broader stakeholders of the benefits of responding to uncertainty through risk management – and of the dangers of failing to do so. A shared understanding of the concepts of uncertainty and risk in the context of water resources management, and the allocation and provision of water resources to meet the many uses they need to satisfy, can serve as a basis for further analysis. Collecting and sharing data are another essential element. With these complementary tools in hand, analysis of the impacts of external forces can be broadly inclusive, involving experts from multiple disciplines. Their experiences, both positive and negative, provide options to those who now need to decide how to act. What interventions are water managers willing to make without the assurance that risk and uncertainty will in fact be reduced? Most decision-makers base their choices on some variation of an ex-ante benefit-cost analysis when it comes to water resources (Shaw and Woodward, 2008). However, it is the benefits rather than the costs that are hard to estimate and which make policy-making regarding water so uncertain. As a result, decision-makers may be able to estimate the costs that their interventions will impose, but the advantages of such interventions may remain uncertain.

This chapter illustrates some responses to dealing with uncertainties in the planning, design and operation of water supply and pollution control systems, when attempting to meet changing demands. These responses usually involve the use of various tools to identify and evaluate alternative water resources plans, policies, infrastructure designs and operating rules applicable to different regions of the developed and developing world. These responses and their outcomes illustrate both successes and difficulties in meeting desired water planning and management goals, and demonstrate the relative effectiveness of associated data collection, generation and management schemes in supporting decisions. They also illustrate how technologies have been used to address issues related to adaption to change and dealing with risks and uncertainties.

This chapter also addresses the need to make decisions under increased uncertainty resulting from abrupt changes, discontinuity and unpredictability. While some of these may pose additional risks, others may provide opportunities. Decision-makers can draw on examples of how some uncertainties and risks are being managed – successfully and unsuccessfully – including through adaptation. Finally, this chapter examines the trade-offs that governments are prepared to make in the face of risk and uncertainty. The following sections do not purport to provide an exhaustive inventory of all possible responses to risk and uncertainty implemented by water managers, but rather seek to provide illustrations of various ways in which risks and uncertainties related to water have been reduced or mitigated.

13.1 Reducing uncertainty

One of the most direct ways of reducing uncertainty is to generate new knowledge or understanding of conditions governing water availability and quality in the present and in the future. Data collection, analytical capacity and predictive ability are all required to reduce uncertainty and therefore to facilitate decision-making about allocations, uses, mobilization and treatment. While the risk to water is not reduced, it is better understood.

Given the multiplicity of factors that could potentially affect water directly and indirectly, this exercise is not as straightforward as it may seem; otherwise no country or user would ever have been surprised by a water crisis. The following section provides examples of means by which this uncertainty has been reduced, or the risks better understood.

13.1.1 Monitoring, modelling and forecasting to reduce uncertainty and understand risk

As technology evolves, tools for predicting future water availability become more refined, allowing for the consideration of multiple variables and drivers. Chapter 6 of this report elaborates on various aspects of data and information in water resources, including the challenges that confront water resources management. Regular monitoring and basic data collection serve as a basis for deriving linear trends as well as to develop more complicated models.

A multi-disciplinary approach can be useful to achieving realistic projections, since it integrates the tools and participation of ecologists, engineers, economists, hydrologists, political scientists, psychologists, and water resources managers, among others. Involving parties from these different sectors permits greater insights into how to manage water resources in the face of risk and uncertainty. Given the interconnectedness of water with other sectors, inclusion of different kinds of expertise can help provide some degree of clarity to uncertainty and risk.

It is commonly recognized that solving water resources problems 'requires the integration of technical, economic, environmental, social, and institutional aspects into a coherent analytical and management framework. Since the 1960s, computational frameworks that combine optimization and simulation tools have been used to develop and assess water resources development strategies for decades. While these prior works have produced significant advances in understanding interactions between economic objectives and physical constraints, consideration of the complexity of the systems has been relatively narrow' (Mayer and Muñoz-Hernandez, 2009, p. 1177). Box 13.1 illustrates the use of a less narrow multidisciplinary tool, which provides many benefits, but highlights the challenges that uncertainty and risk can bring, despite comprehensive analyses and modelling.

13.1.2 Adaptive planning in anticipation of fluctuating risks and uncertainties

Adaptive planning and management are sensible and pragmatic approaches that water managers can use under conditions of change, increasing uncertainty and risk. Adaptive management is often employed to decrease uncertainty and optimize decision-making, while ensuring learning from the process. Adaptive planning and management integrates project design, management, monitoring and evaluation for the purposes of testing assumptions, and learning from the outcomes. Essentially, adaptive planning is based on a 'learning by doing approach' (Kato and Ahern, 2008).

BOX 13.1

Integrated Water Resources Optimization Models (IWROMs)

Integrated water resources optimization models (IWROM) are tools that have been developed over the last decade for determining optimal water allocations among competing sectors. IWROMs use optimization methodologies to find the most efficient water allocation strategies from an economic viewpoint, usually while considering the environmental impact of these strategies. Models of economic benefits associated with the consumption of water in various use sectors are derived and assembled in an objective function, including economic benefits associated with the environment. Hydrological simulation models provide values of state variables, which are needed to evaluate the economic benefit models, constrain the physical system, and, in some newer cases, provide state variables for evaluating environmental impacts. The simultaneous evaluation and consideration of allocations across various water sectors, economic benefit models, models of the biophysical system, and economic and environmental impacts constitute the basis of the integrated nature of IWROMs.

IWROMs seek to find water-allocation strategies that occur in an efficient way, by maximizing the economic benefits or by minimizing the costs or number of people affected by such strategies. In addition, IWROMs allow for testing of different future scenarios that could be experienced by a particular region. These scenarios include potential changes in climate, land cover and land use, improvement of infrastructure, population, and consumer preferences. By testing these scenarios, the stakeholders can anticipate the potential environmental or economic consequences related to specific decisions taken in the basin.

IWROMs are particularly useful for regions where competition for water is intense, valuation of water for the various use sectors can be estimated, economic and operational impacts of proposed management alternatives are of interest, and data are available to calibrate supporting models. IWROMs allow for the simulation of and assessment of water resources economic policies and investments in water infrastructure. IWROMs seek to depict coupled human–nature relationships and mimic the impact of driving forces and feedbacks from the environment so they can effectively analyse sustainability. IWROMs support basin-wide decision-making since appropriate biophysical models can reflect spatial heterogeneity in [hydroclimatic] conditions and water uses among different subregions.

[IWROM applications use hydrological simulators and] mathematical methods to solve optimization problems. It is suggested that IWROMs (a) seek to model coupled human–nature relationships and mimic the impact of water resources management strategies on the environment at the basin scale; (b) allow for the simulation and assessment of economic policies and strategies on water resources management; (c) can support basin-wide decision-making; and (d) are particularly useful for water-scarce regions.

[However, as efficient as IWROM may be, uncertainty poses several challenges to its application. For instance,] specifying sources of error and making accurate estimates of uncertainty in the outputs of IWROMs can be very difficult (Jakeman and Letcher, 2003). Sources of error in individual models may be difficult to identify and quantify, as is the case in the hydrological simulators and economic models used in IWROMs, where the lack of data for model calibration and validation is commonly an issue. Because of the breadth and complexity of issues involved in an integrated model, 'the level of uncertainty goes beyond unexplained randomness to a situation where many things are fundamentally unknowable in a traditional, objective, scientific sense' (Rothman and Robinson, 1997, cited in Jakemen, and Letcher, 2003). In addition, it is often that case that the propagation of errors through the IWROM is poorly understood, due to the complexity of feedbacks within the integrated system. Appropriate processes for validating IWROMs have yet to be fully developed; however, in a few cases, researchers have at least attempted to calibrate IWROMs to historical water demands (Cai and Wang, 2006; Draper et al., 2003).

All of these issues indicate that applications of IWROMs must be sensitive to the effects of uncertainty on the model results and more sophisticated approaches may be needed to quantify uncertainty. Furthermore, models tend to be used to investigate scenarios that can be very different from the situation in which the model was calibrated and tested. The validity of the IWROM or component models outside these circumstances may be questionable and the level of uncertainty in predictions may be difficult to quantify. Rational procedures for choosing planning periods in IWROM applications, which have ranged from 10 to 30 years, have not been established. The value of long-term applications of IWROMs is questionable, given the considerable uncertainty in many modelling aspects, especially the prices and costs include in the economics models. Scenario analysis, [as referred to in Chapter 8,] may be used to explore model uncertainties in these cases. However, formulating realistic scenarios may be difficult, considering that temporal trends in many of the phenomena quantified in these scenarios (such as climate, land use and population change) may be non-stationary.

Source: Reproduced from Mayer and Muñoz-Hernandez (2009, pp. 1176, 1187–8, 1191–2).

As Kato and Ahern (2008) note, the key concepts and principles of adaptive management in the literature and application review are: '(1) conceiving management actions as experiments; (2) conducting several plans/experiments at once for fast learning; (3) monitoring being the key; and (4) learning by doing.' Adaptive management is thus a social process as well as a scientific one, where stakeholders play a key role in informing the learning process (Chapters 5 and 11).

Adaptive management embeds uncertainty as a fundamental principle in the management approach. Adaptive management strategies allow decision-makers to alter the direction of projects and programmes due to emerging information gained by the learning-by-doing approach.

There are some challenges to using adaptive management. These include forgoing short-term advantages for long-term objectives, as well as the demands that are placed on stakeholder participation. Stakeholders are expected to maintain their level of engagement over the long-term, which may not be possible (Lockwood et al., 2006). There are circumstances under which adaptive management is seriously compromised and does not work, for example, when monitoring is not fully completed, when monitoring data is not analysed or accurately assessed, or when the results are inconclusive (Moore and McCarthy, 2010). Moreover, if the process does not have participation of key stakeholders, adaptive management will not yield optimal results.

Because decisions made outside the water domain also affect the resource and its use, many perceive an integrated adaptive approach as the most appropriate basis for managing water systems sustainably. Adaptive water management is an extension of integrated water management in that it is designed to address future uncertainties in a comprehensive fashion. The inclusion of feedback mechanisms in response to changing conditions and increased knowledge is critical for revising and updating integrated water management efforts; adaptive modelling considers both human and ecosystem water needs and takes feedback mechanisms into account.

For example, studies carried out in the Netherlands to support long-term water management planning, in the light of uncertainty regarding climate change impacts, focused on three aspects of water management: flood defence, drinking water supply and protection of Rotterdam Harbour. The key point of interest was whether, and for how long, current water management strategies would continue to be effective under different climate change scenarios. To this end, the studies employed the concept of 'adaptation tipping points' (see Chapter 8, Section 8.1.5). If the magnitude of change was such that a current management strategy could no longer meet its objectives, the study assumed that the tipping point had been reached and that an alternative adaptive strategy was needed. Therefore this approach combined both modelling and forecasting elements with those of adaptive management, providing an iterative process to consider the validity of management approaches. Triggers, or tipping points, are an effective way of evaluating various management milestones, and if agreed upon and recognized by stakeholders outside the realm of water management, can provide an effective rallying point for making decisions about water, while including all users.

> "Adaptive planning and management integrates project design, management, monitoring and evaluation for the purposes of testing assumptions, and learning from the outcomes."

A similar concept has been applied in many instances under the broader heading of disaster risk management (DRM), where emergency triggers can be considered as the equivalent of 'adaptation tipping points'. Indeed, DRM provides a framework for rapid adaptive management based on a set of agreed management changes that occur under specific

BOX 13.2

Adaptive management: Adaptation tipping points in current Dutch flood management

To ensure safety against flooding, safety levels for all flood defences in the Netherlands must be able to withstand a storm event with a certain frequency, as well as maintain the morphological boundary conditions for dune growth along the coast. Optimization of both sand mining and nourishment must be able to meet ecological requirements. Thus, even in the most extreme sea level-rise-scenario, the existing policy of protecting the sandy coast is not likely to encounter an adaptation tipping point (ATP). Potential ATPs might arise on the social and political level, however. For example, the social acceptability of living behind giant dykes might decline, and increasing spatial claims of ever-larger dykes might provoke changes in governance arrangements.

The Maeslant Barrier is essential to protecting Rotterdam Harbour and its tidal river area against flooding. The dykes in this region are designed to withstand water levels that have a probability of occurrence between 1/10,000 and 1/4000 annually. To meet this safety level, the barrier closes if the water level at the outlet of the waterway exceeds 3 m or exceeds 2.90 m upstream at Dordrecht. The return period of such an event is approximately 10 years. Rising sea level implies that the barrier will close more often. However, closing the Maeslant Barrier hinders navigation to and from Rotterdam Harbour. According to the Rotterdam Port Authority a maximum closing frequency of once per year is acceptable. This is considered an ATP. The closing frequency of the Maeslant Barrier depends on the sea water level, the duration of storm events, and the discharge of the rivers. Another ATP is the maximum sea level rise the barrier has been designed for, which is 50 cm.

The tidal river area is crucial for freshwater provision (drinking water and agriculture) in the southwest of the Netherlands. Rising sea level and reduced river discharge during dry summers lead to extra salinization of groundwater and surface water. An ATP for this sector would occur if sea level rise in combination with lower river drainage were to result in an inability to maintain salt concentrations at a level low enough to maintain key functions. Water allocation has been established in a series of water agreements between national and regional administrations. To meet the requirements, the maximum allowable chloride concentration in the inland water system is 250 mg per L. Under current conditions, the freshwater inlet needs to be closed once between every five and 10 years to protect against saltwater intrusion. However, the frequency and duration of necessary closure of freshwater inlets rapidly increases with rising sea levels and decreasing river discharges.

Source: Kwadijk et al. (2010).

conditions. This is not a new approach, but one that functions with varying degrees of effectiveness depending on the context. The successful operation of a rapid and flexible DRM system requires a number of basic functions such as availability of data, the technical means for monitoring, and rapid response systems, which are not always functional in all countries. In this case, however, uncertainty is not reduced, but mitigated by the adoption of pre-established management responses triggered by specific events. As highlighted in the 2011 Global Assessment Report published by UNISDR, however, DRM frameworks can help to address other 'non-emergency' needs as well, such as planning for hydro-electricity, agriculture and other water needs. DRM need not be a parallel exercise to other risk and uncertainty reduction initiatives in the water domain. 'However, the examples [Box 13.3] indicate that ecosystem-based disaster risk management is an increasingly attractive option for addressing problems as varied as river-basin and urban flooding, drought and wildfires.' (UNISDR, 2011, p. 127)

Another tool used in dealing with disasters from a planning and risk management perspective is catastrophe modelling, as described in Box 13.4.

13.1.3 Proactive management

Another way of dealing with risk and uncertainty in water management is to anticipate the future conditions of a number of key drivers, chief among them demand for water. Analysis of the determinants of water demand can provide useful avenues for reducing some water uncertainties, and many countries have adopted demand management as a mechanism for water allocation, management, conservation and planning. Water demand has been on the rise for a number of years, particularly in urban areas, and projections show continuing growth in demand (Butler and Memon, 2006). The chief influencing factors are the drivers referred to in Chapter 2, including population growth, migration, lifestyle and economic changes, demographic shifts and the impacts of climate change. All of these drivers create conditions of uncertainty and challenges to meet the increasing demand. Demand-side management, as highlighted in Chapter 5, addresses consumptive demand so as to postpone or avoid the need to develop new resources (Butler and Menon, 2006), thereby limiting the uncertainties and risks emerging from unbridled water demand and potential shortages in the future.

BOX 13.3

Risk-addressed examples

River basin flooding

In Hubei Province, China, a wetland restoration programme reconnected lakes to the Yangtze River and rehabilitated 448 km^2 of wetlands with a capacity to store up to 285 million m^3 of floodwater. The local government subsequently reconnected a further eight lakes covering 350 km^2. Sluice gates at the lakes have been re-opened seasonally, and illegal aquaculture facilities have been removed or modified. The local administration has designated lake and marshland areas as nature reserves. In addition to contributing to flood prevention, restored lakes and floodplains have enhanced biodiversity, increased income from fisheries by 20–30% and improved water quality to potable levels (WWF, 2008).

In 2005, the Government of the United Kingdom launched the programme Making Space for Water, an innovative strategy that uses ecosystems instead of costly engineered structures for flood and coastal erosion risk management along river banks and coastlines. The programme, triggered by severe floods in 1998, 2000 and 2005, consists of 25 nationwide pilot projects at the catchment and shoreline scales, and involves collaborative partnerships between local governments and communities. Since April 2003, the Government has invested between US$4.4 and US$7.2 billion as of March 2011. One such project covered an area of approximately 140 km^2 of the Laver and Skell Rivers west of Ripon in North Yorkshire. Activities included planting trees as shelterbelts, establishing vegetative buffer strips along riverbanks, the creation of woodland, fencing off existing woodland from livestock, hedge planting, and creation of retention ponds and wetlands for increased flood storage capacity. These activities reduced surface flow during floods by trapping, retaining or slowing down overland flow and provided other benefits such as protection of wildlife habitats and improved water quality (PEDRR, 2010).

Urban flooding

Urban development replaces vegetated ground that provides a wide range of services, including rainwater storage and filtration, evaporative cooling and shading, and greenhouse gas reduction, with asphalt and concrete, which do not. Although the functions of green spaces in urban areas are easily overlooked, local governments have started reinstating 'green infrastructure' (Gill et al., 2007) as a viable component of urban water management and as a means of combating urban heat. In New York, for example, untreated storm water and sewage regularly flood the streets because the ageing sewerage system is no longer adequate. After heavy rains, overflowing water flows directly into rivers and streams instead of reaching water treatment plants. The US Environmental Protection Agency has estimated that around US$300 billion would need to be invested over the next 20 years to upgrade sewerage infrastructure across the country. In New York City, alone, it is estimated that traditional pipe and tank improvements would cost US$6.8 billion (New York City, 2009). Instead, New York City will invest US$5.3 billion in green infrastructure on roofs, streets and sidewalks. This promises multiple benefits. The new green spaces will absorb more rainwater and reduce the burden on the city's sewage system, air quality is likely to improve, and water and energy costs may fall.

Drought

Two different but almost simultaneous agro-ecological restoration processes that started 30 years ago in southern Niger and the central plateau of Burkina Faso have increased water availability, restored soil fertility and improved agricultural yields in degraded drylands. With very little external support, local farmers experimented with low-cost adaptations of traditional agricultural and agroforestry techniques to solve local problems. Three decades later, hundreds of thousands of farmers have replicated, adapted and benefited from these techniques, transforming the once barren landscape. In Burkina Faso, more than 200,000 ha of dryland have been rehabilitated, producing an additional 80,000 tonnes of food per year. In Niger, more than 200 million on-farm trees have been regenerated, providing 500,000 additional tonnes of food per year, as well as many other goods and services. In addition, women have particularly benefited from improved supply of water, wood fuel and other tree products (Reij et al., 2010).

Aboriginal people in northern Australia have a long history of using fire to manage habitats and food resources. Due to changes in settlement patterns and marginalization, traditional fire management was fragmented over vast areas, leading to an increase in destructive fires in fire-prone savannahs. Traditional fire management practices, such as early dry-season prescribed burning, have been revived and combined with modern knowledge, such as using satellite technology to locate fires.
Aboriginal fire rangers have considerably reduced large-scale fires through fire management across 28,000 km^2 of western Arnhem Land, with subsequent reductions in greenhouse gas emissions of more than 100,000 tonnes of CO_2-equivalent per year. The Darwin Liquefied Natural Gas plant compensates aboriginal communities with approximately AU$1 million (US$1 million) per year for offsetting carbon, generating important income in disadvantaged communities. Additional fire management benefits include protection of biodiversity and indigenous culture (PEDRR, 2010).

Source: Reproduced from UNISDR (2011, p. 129).

For example, demand management is a key element in the United Kingdom government's sustainable development policy. The government has implemented this policy by enacting the Green Deal. This encourages efficient use of water in homes and business through delivering joint energy and water savings; promoting investment by water and sewerage companies of UK£22 billion by 2015; and developing new assets and innovative technologies (EA, 2011).

A water-demand programme was also implemented in South Africa. The objective of the Greater Hermanus Water Conservation Programme was to conserve the natural water resource against increased demand using a comprehensive long-term water conservation programme. It was based on a series of principles including: water-loss management to deal with unaccounted for water such as unmetered and illegal connections and leakage; retro-fit programmes to supply existing homes and buildings with water-saving devices (owners were fined if devices were not installed after a certain period of time); school audits to find out what activities consume the most water and why; assurance of supply with a fixed amount levied every month, forming the basis of the authority's pledge to provide water to every house as long as it is available; escalating block-rate tariffs; water-wise gardening methods; the use of 'grey' water for food production; and the creation of water regulations and building by-laws (WMO, 2001).

BOX 13.4

Catastrophe modelling as a tool for understanding and calculating risk in the insurance industry

Catastrophe modelling is a tool developed by private sector companies, working in the insurance sector, as a 'mechanism to integrate and synthesize all the relevant science, data, engineering knowledge and even behaviour of claimants and insurers in the aftermath of a catastrophe' (Shah, 2008, p. 5). Today, it has evolved into a risk identification and prevention tool. The approach, which combines mapping risk and measuring hazard, came together in a definitive form in the late 1980s.

> While it is generally agreed that a probabilistic approach is the most appropriate method to model the complexity inherent in catastrophes, probabilistic modelling itself is multifaceted. It requires simulating thousands of representative, or stochastic, catastrophic events in time and space; compiling detailed databases of building inventories; estimating physical damage to various types of structures and their contents; translating physical damage to monetary loss; and, finally, summing over entire portfolios of buildings. ... Catastrophe models require substantial amounts of data for model construction and validation. (Grossi and TeHennepe, 2008, p. 7)

Originally intended as tools reserved for the calculation and projections of financial losses within the insurance industry, catastrophe models are increasingly being used by governments and municipalities as a risk management and prevention tool. Catastrophe modelling provides an integrative model whereby eventual losses can be quantified and trade-offs analysed towards the integration of adaptive measures in planning.

Source: The Review (2008).

Although managing water demand is one way of limiting risks associated with increasingly uncertain levels of consumption and potential future shortages, it also poses some unforeseen challenges. For example, water demand management calls for a good understanding of who is making the demands on water and how much they are demanding. This requires considerable knowledge and information, without which policies may target suboptimal sectors or users, thereby having a negligible impact on future risks. Improvements in resource monitoring and databases of water use information are therefore required. In turn, these valuable new resources can be used to produce improved forecasts of water demand, so that planning procedures are able to guarantee water supplies to more people – especially the poorest members of society who are traditionally hardest hit by water shortages (WMO, 2001).

Another challenge is that as policies address the need for demand management, new issues arise regarding recognition of the environment as a user. Traditionally, the environment has been neglected, but with the National Water Act in South Africa, for example, comes the concept of an 'environmental reserve', designed to protect the ecosystems that underpin water resources. The Act also states that it is the duty of the Government 'to assess the needs of the environmental reserve and to make sure that this amount of water, of an appropriate quality, is set aside' (DWA, 1997). This approach has immense impacts on water resources management in South Africa, but raises the difficult question of how much environmental reserve a river or water resource requires (WMO, 2001).

An additional challenge that demand management raises, and which limits its ability to minimize risk and uncertainty, is the necessary participation of various stakeholders at different levels. It requires community buy-in, commitment, monitoring and adherence to the paradigm of demand management. It also requires transparent flows of information, for example, to address unknown users, such as illegal water connections, leakages and other losses, that are not attributable, but which bring an additional layer of uncertainty and risk to the equation.

However, integrating a participatory dimension to demand management can `democratize' the process of determining and prioritizing risks and uncertainties (Baroang et al., 2010). Including various stakeholders can also balance their multiple needs, and inform policy formulations and management responses that respond to them, as illustrated by the example in Box 13.5.

BOX 13.5

Farmer managed groundwater systems in Andhra Pradesh, India

The Andhra Pradesh Farmers Ground Water Management System (APFAMGS) is a community-based project involving over 28,000 men and women farmers in 638 villages across 7 drought-prone districts. The project focuses on developing the capacity of groundwater users in managing their resource in a commonly sustainable way. The project adopted a demand side approach to groundwater management, wherein farmers are made to understand how their groundwater system functions so that they can make informed decisions about their water use. The core concept or belief of APFAMGS is that sustainable management of groundwater is feasible only if users understand its occurrence, cycle and limited availability, and they accept that groundwater conservation through collective decisions is ultimately a safeguard of their own interest. Thus, the burden of control of extraction is transferred to individuals in communities who know the 'why and how' and act based on sound information, rather than being enforced by government imposed rules and regulations.

The project emphasizes sustainable use of shared water resources, while promoting capacity development of groundwater users. The demand-side approach to the project allows farmers to manage their water resources, understand how groundwater systems operate, and make informed choices regarding their water use. The underlying premise of APFAMGS is that sustainable management of groundwater is feasible only if users understand its occurrence, cycle and limited availability, as well collective decision-making, which will govern the resource. Extraction is thus practiced by individuals in communities who know the 'why and how' of their practices, and base their decisions on sound, collective information, rather than being subject to government laws and regulations.

The project does not offer any financial incentives or subsidies. Rather, the assumption of the project is that access to scientific data and knowledge will enable farmers to make appropriate choices and decisions regarding the use of groundwater resources.

The objective is to equip farmers with the necessary knowledge, data and skills to manage the groundwater resources available to them in a sustainable manner, mainly through controlling demand. The project also facilitates access to information about irrigation water-saving techniques, improved agricultural practices and ways to regulate on-farm demand for water. Unlike most other attempts at centrally based groundwater management, APFAMGS does not seek an agreement from communities to reduce their groundwater use – farmers are free to make crop planting decisions and extract groundwater as they desire, and there is no collective agreement by communities on self-regulation of groundwater use. The project therefore relies solely on the impact of groundwater education to influence individual decisions of thousands of farmers regarding crop selection and irrigated areas in the post-monsoon season.

The project has been successful in that the groundwater supplies have provided a sustainable source of water for the farmers. Even though it is possible, no farmer or group of farmers has depleted the groundwater supply. A number of factors have contributed to the success of this project, two of which are the timely availability of current data on the status of groundwater availability and projected demand, enabling informed planting decisions – a key input to the farmer's risk management paradigm, and reductions in groundwater overdraft resulting from multiple individual risk-management decisions of farmers. As a result, authoritative leadership is unnecessary for enforcement (GWP, 2008).

Source: APFAMGS (2008); World Bank (2010).

13.2 Reducing exposure to threat and minimizing risks

If the examples in the preceding boxes illustrate various approaches used in attempting to reduce uncertainty, other tools exist that allow for the reduction of risks. The key approach is to analyse the various factors of risks, including the probability of certain events or triggers, and to reduce or eliminate exposure to such risks for water resources and for communities who depend on them.

13.2.1 Investments in infrastructure

New, updated and expanded water resources infrastructure can reduce the risks associated with climate change, hydrological variability and their impacts on water resources and systems. Adding new infrastructure can potentially take advantage of new technology. For example, while in some regions reservoirs are being removed to reduce the risks to ecosystems, including fish, the development of increased water storage capacity, particularly to reduce water scarcity risks and manage floods in other regions, appears inevitable in the light of highly likely water shortages.

There are various types of infrastructure that states can invest in to address the challenge of risk and uncertainty. One response option for reducing the variability and uncertainties of natural stream and river flows is to construct reservoirs designed and operated to redistribute water over time and space in ways that better meet human and environmental needs in comparison to the natural flow regime. Reservoirs are controversial. Many are being planned and built in water scarce or energy deficient areas of the world, while in other areas they are being removed in an effort to restore ecosystems. Dams and reservoirs are essentially risk-avoidance tools, based on a knowledge of current conditions and variability.

For example, the International Water Management Institute (IWMI) predicts that climate change will have dire consequences for feeding an ever-expanding global population, especially in areas of Africa and Asia where millions of farmers rely solely on rainwater for their crops. In Asia, 66% of cropland is rainfed, while 94% of farmland in sub-Saharan Africa relies on rain alone, according to IWMI. These are the regions where water storage infrastructure is least developed and where nearly 500 million people are at risk of food shortages.

IWMI suggests that the solution is to fund a diversity of water storage projects, from small-scale rainwater tanks and larger-scale dams to systems that artificially recharge groundwater aquifers, to improve the soil so it can hold more water. Stored water in times of drought can lead to increased food security. 'Just as modern consumers diversify their financial holdings to reduce risk, smallholder farmers need a wide array of 'water accounts' to provide a buffer against climate change impacts' (McCartney and Smakhtin, 2010; quotation from IWMI, 2010, p. 1).

Small-scale storage projects have delivered some positive results when planned with the participation of both politicians and farmers. For example, small collection basins have boosted maize yields in times of rain or drought in Zimbabwe. In India's Rajasthan State, 10,000 water harvesting structures that help to recharge groundwater now irrigate 34,600 acres (14,000 ha) and feed 70,000 people (Eichenseher, 2010). In India, where there is expected to be a 50% gap between water demand and supply by 2030, decision-makers are starting to fund storage projects because they recognize the long-term economic benefits of a secure supply (IWMI, 2009).

Investing in infrastructure for future risk reduction can also have its trade-offs and unforeseen consequences. For instance, in the case of the Savannah River in the United States of America, the construction of three dams and reservoir systems just 50 years ago has negatively altered the natural flow patterns that support the wildlife, natural communities of the river, its estuary and floodpath. This is of particular concern given that the lower Savannah River watershed supports extremely high species diversity, including the greatest number of native fish species (108) of any river draining into the Atlantic (Hickey and Warner, 2005). An infrastructure approach thus has to examine all aspects of risk and functions of water. Only at that point can water managers make decisions with the most advantageous trade-off – with the best possible picture of uncertainty and risk.

The example of the Savannah River reveals that positive outcomes ensue when the iterative, consultative approach is used. In 2002, the US Army Corps of Engineers (USACE) and The Nature Conservancy (TNC) launched the Sustainable Rivers Project to restore the river (Hickey and Warner, 2005). The main strategy was to define flow regimes that restored downstream ecosystems processes and services, while continuing to meet other human uses of water such as power generation (provisioning service), recreation (cultural) and flood control (regulatory). The project began in April 2003 with an orientation meeting with more than 50 leading scientists from the Georgia and South Carolina state governments, federal agencies, academic institutions and other non-governmental organizations to define the process. Historical data was used to define the seasonal water flows needed to support the freshwater, floodplain and estuary. It was difficult to get the participants in the flow recommendations workshops to suggest any quantitative flow targets. However, once reminded them that their recommendations were a first approximation that would be refined over time through an adaptive management process, the targets were established. Working with many scientists and agencies can be onerous and time-consuming, but most of these constraints were avoided by giving the most time-consuming activities to one research team. This report became the accepted basic knowledge for other scientists in the project, making it easier to reach consensus during the flow recommendations workshop.

Eventually a flow prescription plan for executing a series of seasonal controlled releases was designed and tested. For five days, USACE released the first

BOX 13.6

Mangrove restoration in Viet Nam

Viet Nam has lost over 80% of its mangroves since the 1950s. The two major causes are the use of defoliating agents during the Vietnam War and the rapid expansion of the aquaculture industry during the early 1980s. Mangrove restoration and rehabilitation has been ongoing since 1991 as a policy response to this loss. The underlying goal of restoration and rehabilitation is to mitigate the impact of sea level rise and coastal storms. Yet with respect to the restoration of mangrove forests, stakeholders have a diverse set of interests and diverging priorities and preferences.

Viet Nam is extremely vulnerable to climate change. Climate change scenarios from different institutions indicate vastly different trends for precipitation, with some projecting decreases and some projecting increases, thus creating climatic uncertainties. Projections also suggest that there will be an increase in frequency and intensity of tropical storms, and that sea level will rise.

Clearly there is a high degree of uncertainty in these climate change projections. However, even in the absence of the changes suggested by these projections, the country's agriculture and water resources are increasingly vulnerable to impacts from saline intrusion and flood inundation. Climate change could result in seawater intrusion into groundwater, which provides valuable freshwater supplies for many coastal areas. Rapid conversion and drainage of wetlands, combined with changes in water flows connected to upstream infrastructure developments, may increase the incidence of floods and droughts. Storm surges can also severely damage coastal infrastructure and the dykes and structures that support the rapidly developing aquaculture industry. Tidal mixing associated with floods and storm surges leads to saline concentrations that have a widespread impact on terrestrial and aquatic ecosystem goods and services, in particular native species and species with high economic value.

In contrast to stand-alone measures such as dykes, mangrove restoration and rehabilitation has been promoted as a 'low/no regret measure'. It can be applied as a precautionary approach to climate change adaptation and foster 'win–win' situations by addressing present multi-sectoral vulnerabilities and future risks. In northern Viet Nam the focus of mangrove restoration and rehabilitation is disaster risk mitigation, and thus its protective function is prioritized. Most of the forests in this region are classified as 'protection forests', owned and managed by the government. In the South, mangrove restoration and rehabilitation has in many cases been promoted as a development action to meet multiple objectives. 'Planted production forests' can be privately owned, with the owner having 'all right to use of forestland including development of combined agriculture-fishery-forestry model'. This regional differentiation in function or purpose is perhaps not surprising given that northern Viet Nam lies in the typhoon belt and is thus most exposed to structural damage from storm surges.

The implementation of mangrove restoration and rehabilitation, nested within a no/low-regret action planning process, is more likely than any single objective approach and stand-alone measures to secure a greater set of benefits across stakeholder groups, even in a future characterized by uncertainty (Mangrove Action Project, 2008).

Source: APFAMGS (2008); World Bank (2010).

controlled flood of 450 m^3 per second (cms) of water from the Thurmond Dam, a sizable increase from the existing daily release of 130 cm. Several controlled floods have been conducted from March 2004 to the present time. These controlled releases mimic pre-existing flow conditions before the dams were built. There have been numerous ecological impacts that have been evaluated by various projects – most notably the ability to monitor changes. These include: assessing impacts of controlled floods on the salinity of the estuary, examining the possibility of regenerative benefits to floodplain forest, following the movement of the shortnose sturgeon, and tracking floodplain invertebrates and fish. Such monitoring provides great insights to stakeholders and yields greater information on possibilities of wildlife preservation.

BOX 13.7

Constructed wetlands for wastewater treatment in Bayawan City, Philippines

The ability of wetlands to filter and transform nutrients and other constituents has resulted in the construction and use of artificial wetlands to treat wastewater and acid mine drainage (Hammer, 1989, 1992; Wieder, 1989). Such a wetland was constructed in Bayawan City – the first of its kind in the Philippines. It was designed to protect coastal waters from pollution from domestic wastewater, protect the health of local residents through improved housing with safe sanitation and wastewater treatment facilities, and to demonstrate the use of constructed wetland technology as a pilot for other communities in the Philippines.

The project took place in the south-west of Negros Island, covering a total land of 70,000 ha with a population of about 113,000. The project was located in a peri-urban area of Bayawan, which has been used to resettle families that lived along the coast in informal settlements, and had no access to safe water supply and sanitation facilities. Records from the City Health Office showed a high incidence of morbidity and mortality arising from water-borne diseases in these informal settlements.

Both the village and the constructed wetland are close to the seashore and during the rainy season groundwater rises to ground level. The project involved creating cells built of concrete and concrete blocks with a drainage system positioned at the bottom of each cell. These cells were covered by a separation layer and then a filter layer. The plants used in the filter are a species of locally available reed called 'tambok' (*Phragmites karka*). The reeds also act as an odour barrier during the filling process.

The wastewater distribution system is composed of four concrete header tanks and a system of perforated high-density polythene (HDPE) pipes. The system is manually operated comprising the switching on and off of the pump and the emptying of the header tanks into the distribution system. The header tanks are filled two to three times a day. Since coming into operation, the system has been continuously improved. The header tanks were covered to minimize odour during the filling process, and the collection sumps between the two wetland cells and after the second cell were covered to reduce algae growth. In addition, a large storage tank was built for the treated wastewater.

The local water service provider regularly analyses the influent and effluent of the constructed wetland. This analysis includes TDS, pH, BOD, ammonia, nitrate and phosphate, as well as the microbiological parameters *E. coli*). The analysis of the treated wastewater showed very good pollutant removal efficiency (97% removal of BOD).

The treated wastewater was initially used in construction, for concrete production, which reduced construction costs. It is now also used for an organic cut flower and vegetable farming project introduced in the region. Only a basic microbiological analysis on the effluent from the constructed wetlands was conducted. However, since November 2008, more frequent and accurate monitoring has been conducted to analyse for faecal coliforms. The effluent has almost ideal concentrations of nitrate and phosphate to be used for 'fertigation' (fertilizer plus irrigation) for the vegetable and cut flower project. The more advanced analysis of total coliform, however, showed that the pathogen concentrations remain too high for unrestricted irrigation, but demonstrated that the total coliforms concentration in the treated effluent is still lower than in virtually all the rivers of Negros Oriental (approximately 10,000 – < 100,000 CFU per 100 mL in rivers). The investment in this constructed wetland infrastructure consequently provides water resources for various economic activities, which would otherwise be compromised, thereby reducing uncertainty (Lipkow and von Münch, 2009).

Source: APFAMGS (2008); World Bank (2010).

13.2.2 Environmental engineering

The natural environment can also be considered as 'infrastructure', as it supplies many of the same services as man-made infrastructure (see Section 8.3). Wetlands, for example, can reduce peak flood flows and assimilate many organic wastes in the same manner as wastewater treatment plants. Humans often ignore ecosystem water needs in allocating water resources, thereby risking the sustainability of life-supporting ecosystem services. Increased research and monitoring regarding ecosystem water requirements will help planners and managers use the natural environment as a component of water resources infrastructure. Infrastructure planning, particularly investing in ecosystems, can also take a no-regrets approach by anticipating greater variability, and planning for sustainability.

Although the uncertainties around natural disasters may be addressed by investing in physical infrastructures, examples exist where strengthening natural ecosystems can mitigate some of the challenges posed by natural variability. The following responses to flood damage reduction illustrate this and demonstrate that strengthened ecosystems can create greater support mechanisms in the face of weather-induced uncertainties and risk. Natural ecosystems are also options for flood damage reduction, as discussed in Section 8.3.

Stakeholders other than the states can carry out investments in the environment. As the following example of India and Brazil demonstrates, community-based management can lead to successful investment in and management of environment resources:

BOX 13.8

Community-based watershed management in India and Brazil

Examples of community-based watershed management systems in countries such as India and Brazil provide evidence for the value of involving women's groups in maintaining and protecting their water sources. In semi-arid areas of Gujarat, India, the Self Employed Women's Association (SEWA) created its Women, Water and Work campaign in 1995 to sustain and protect traditional water sources through water harvesting, watershed management, and repair and maintenance of pipelines and equipment. SEWA's collective action approach for women combines the presence of a strong grassroots institution and the establishment of a technical cadre of women. SEWA's membership has increased greatly due to the success of the water campaign. Women have benefited in terms of increased income, reduced drudgery, improvements in the livelihoods of their families, reduced migration of both women and men, and increased participation in SEWA's other programmes. SEWA is a powerful non-governmental organization (NGO) with the capacity to negotiate in the water management area, previously occupied by men only (Panda, 2007).

In the community of São João D'Aliança in central Brazil, the local Union of Rural Workers in collaboration with University of Brasília (UnB) designed a community water project to stop pollution of the das Brancas River and to rehabilitate original vegetation along the riverbanks. In the women-led initiative, called the 'Water Women' project, each group of women adapted environmentally friendly practices to their daily activities. Community education taught local people not to dump their sewage into the river, and how to plant native species of trees along the riverbanks. As a result, there is a visible absence of waste in the river, a considerable growth of new vegetation of native species on the riverbanks and decreased soil erosion. Women's political participation was strengthened, and public perceptions regarding their leadership capabilities were changed (Souza, 2006).

13.2.3 Mondi Wetlands Programme, South Africa

Water is South Africa's scarcest natural resource, and 55% of South Africa's wetlands to date have been lost due to irresponsible agriculture and forestry, urban development, pollution, dam-building, erosion and fire. Moreover, the majority of South Africans do not have access to drinking water and therefore rely on streams, rivers, marshes and other types of wetlands to supply them with enough water to satisfy their needs. If the current supply and demand rates continue, South Africa's water resources will be fully utilised by 2025 (MWP, n.d.).

Based in Centurion (Gauteng) and Howick (KwaZulu-Natal) in South Africa, the Mondi Wetlands Programme (MWP) is a joint programme of South Africa's two largest NGO conservation organizations, WWF-South Africa and the Wildlife and Environment Society of South Africa (WESSA), together with two corporate sponsors, the Mazda Wildlife Fund and Mondi Ltd. Established in 1991, the MWP is the most successful non-governmental wetland conservation programme in South Africa, and is recognized by its partner organizations as pioneering wetland conservation outside reserves in South Africa.

> "In an environment of uncertainty and risk, policy-makers may be inclined to make decisions that offer the highest utility, which in uncertain circumstances, may be the status quo."

In January 2001, the Mondi Wetlands Project launched a communal wetlands programme to help manage and rehabilitate communally used wetlands. The main objective of the programme has been to promote and facilitate the effective participatory management and sustainable use of wetlands in communal areas. The objective was supported by the following working activities: develop partnerships with government extension services and service providers, and build their capacity in wetland management; identify community-based wetland management problems and issues; develop an understanding of community dynamics and perceptions of wetlands; catalyse, build and support institutions that can help develop the capacity of communities to use their wetlands sustainably; and facilitate rehabilitation of degraded wetlands where feasible.

By including the participation of various stakeholders, including government departments, tribal authorities and NGOs, the programme has had many tangible successes. For example, the Mondi Wetlands Programme has initiated the rehabilitation of degraded wetlands in South Africa, on a multi-million Rand scale; assessed the condition of over 30,300 ha of wetlands and initiated rehabilitation in many of these; started wetland conservation activities in 21 core areas around South African outside declared reserves; trained more than 1,050 people from 60 organizations in wetland assessment and functioning; and promoted education regarding wetlands. Community buy-in and stakeholder participation is ensured by lengthy processes: the manager of the communal wetland programme is tasked with creating wetland awareness of wetland issues in rural tribal areas, building capacity and competence of government extension officers, lobbying decision-makers of various institutions to address wetlands conservation, facilitating the establishment of wetland governance structures, and promoting the implementation of better wetland management practices (Rosenberg and Taylor, 2005).

Wetlands play a crucial role in managing water. They perform 'water purification, storage, recharging of underground aquifers and streamflow regulation. They are of further national importance for their control of erosion, flood attenuation and biodiversity value. Presently, wetlands are one of the most threatened and under-managed habitat types in South Africa and the world today' (WWF South Africa, n.d.). However, it can be difficult to invest in wetland protection, particularly for non-state actors. Wetlands are often perceived as having little or no value compared to the other uses of land and waters (Schuijt, 2002). Part of the dilemma is that wetlands do not provide immediate and visible benefits to risk reduction. However, investments in wetlands provide safeguards against future risk and uncertainty. Africa, one of the two regions facing serious water shortages (UNEP, 2002), needs wetlands for the long-term health, safety and welfare of its many communities (Schuijt, 2002).

However, most African wetlands are under threat. Stakeholders can be a significant part of the problem. The fact is that many stakeholders of wetlands hold divergent interests. As a result, claims are laid against wetlands that do not coincide, and wetland resources are often turned over for exploitation (Schuijt, 2002). This is why the Mondi Wetlands Programme is such a notable success: it has managed to solicit stakeholder support across various social levels. In the face of future risk and uncertainty, this investment in wetlands supports the life cycles of wildlife that depend on it, provides natural filtration of water, secures water sources and moderates the effects of future droughts, floods, climate change and erosion.

Stakeholder participation, although a useful approach to manage risk and uncertainty, can also pose some challenges. There is always a risk that stakeholders will be unwilling or unable to participate in water management processes. Although the latter problem can be resolved through effective capacity-building, this requires additional resources. The willingness of stakeholder participation is more difficult to achieve, and can involve slower processes aimed at changing attitudes and values, and promoting education.

13.3 Living with risks and uncertainties: Trade-offs in water decision-making

To meet human and environmental needs for water, water managers have always dealt with the risks and uncertainties arising in part from natural variability. But new issues have emerged, particularly due to climate and land use changes and the often-conflicting pressures from other external drivers. This introduces additional uncertainties and associated risks, making it difficult to evaluate costs and the impacts that policy changes can have. Future actions can no longer be based exclusively on past conditions, particularly considering emerging global-scale phenomena such as climate change, or rapid migration flows. The increasing speed with which some of water's drivers are changing such as consumption, demographics and technology, and possible discontinuities in some of them, are exacerbating unpredictability. Decision-makers may address the uncertainties that climate change imposes in a myriad of ways; one of these ways is to convert the uncertainty into a risk scenario, in other words, to assume that risk exists and factor the probability into the management or policy approach. This, however, requires an accurate understanding of the trade-offs involved in each policy option.

Australia, as shown below, has employed the precautionary approach in the face of climate change. However, as the example displays, governments may opt for precautionary measures to avoid future risks, but policy decisions can have unforeseen outcomes, which may in fact create new uncertainties.

The Australian government developed the National Plan for Water Security to address public concerns over water resources, particularly relative to increasing droughts and fears over future shortages. The 10-point plan aims to spend US$10 billion over ten years on water resources. In efforts to exercise precautionary measures, the largest portion of funding, US$6 billion, is to be spent on engineering solutions to enhance irrigated agriculture, which has been identified as an area where water usage can be improved. The aim behind this intervention is to create water-savings, which can then underpin environmental sustainability. The Plan also sets up a buy-back process to address the issue of over-allocation of water, which has been identified as a cause for concern and a contributing factor to future water shortages.

There are, however, some unforeseen consequences to this plan. Despite investing in engineered and technological fixes, involving engineers at a greater level in managing water resources than farmers may have other implications. Engineering-based solutions may interfere with farm level decision-making, which may perhaps be less efficient than educative practices developed with farmers over the long run. Moreover, despite the affordability of the buyback system as a mechanism to address water allocation, the withdrawal of water from some irrigation uses and the exit of irrigators will leave those remaining in the industry with an unreasonable financial burden due to the less-intense use of irrigation infrastructure (Crase, 2008).

Another unforeseen consequence is that the focus on irrigation water has led to lapses in the legislation regarding groundwater. Legislative policies have restricted access to surface water with the result that groundwater demand is increasing. This leaves policy-makers playing catch up to rein in excessive surface level extraction, while monitoring and controlling groundwater use (Crase, 2008). Groundwater use could thus increase the creation of new water uncertainties and challenges.

This example is an illustration of a willing government trade-off to reduce future water uncertainty and risk. However, there is no certainty of policy outcome, as is demonstrated by the unforeseen consequences highlighted above. In an environment of uncertainty and risk, policy-makers may be inclined to make decisions that offer the highest utility, which in uncertain circumstances, may be the status quo. As some research demonstrates, decision-makers exhibit a strong status-quo bias in the face of uncertainty – a bias that becomes stronger when faced with more options (Samuelson and Zeckhauser, 1988). Faced with the increasing uncertainties regarding water, business-as-usual water management often indicates a de facto trade-off between the satisfaction of immediate needs and longer-term solutions that would involve the loss of financial or political capital in the short term.

Limited water availability, growing and evolving demands, and competition among increasingly scarce financial and physical resources create difficult trade-offs for decision-makers, who must plan effectively under considerable risk and uncertainty. Countries can take precautionary or status quo approaches towards addressing risk and uncertainty, and these reflect the trade-offs they are willing to make to address risk and uncertainty. Policy changes only occur when the costs of maintaining the status quo exceed the transaction costs of implementing change (Saleth and Dinar, 2004). In this vein, countries can view their transaction costs in different ways: some may see the deterioration of water and environmental resources as negative externalities not costly enough for current policy change, while others may view future water challenges as bearing higher costs which require current policy change for future benefit.

However, not all trade-offs need be negative. There are indeed examples of win–win situations where efforts to address risks and uncertainties in and outside the water realm have led to multiple multi-sectoral benefits, and to benefits for water in the long-term. The example below illustrates how a private sector firm, Dow Chemicals, faced with the rising costs of water as an industrial input, pollution control costs and corporate social responsibility issues, managed its own risks in a manner that was beneficial to all water users.

While this chapter has focused on the management of risks and uncertainties from within the water domain, the following chapter highlights examples of how efforts to manage other growing risks and uncertainties can also result in positive or negative impacts on water. As the web of risks and uncertainties grows more complex and as changes accelerate, it will become important to derive management approaches that help deliver multiple benefits.

BOX 13.9

Ensuring reliable access to water for industrial purposes while providing a key pollution control service

Dow is a company specialized in innovative chemical, plastic and agricultural products and services. Its Terneuzen manufacturing facilities in the Netherlands require a significant amount of freshwater. However, the local water is brackish, requiring freshwater to be transported a distance of ~100 km. Because the freshwater is utilized by both industry and municipalities, Dow needs to reduce potentially major business risks of increased scarcity and increased costs of freshwater.

The objective of the Terneuze project is to provide a long-term, cost-effective, reliable supply of water for the industrial site. Development of the ‘household wastewater utilization’ project began in early 2005 with implementation occurring in early 2007. Together with regional partners, the utility provider Evides and the regional Water Board, a robust integrated water management system was created. Thanks to this scheme, the Terneuzen site is now taking the local community’s treated wastewater, which was previously discharged directly into the river, and reusing it twice – firstly for steam production in manufacturing plants and then again in cooling towers – before releasing it into the atmosphere as vapour.

Since 2007, the site accepts more than 9.9 million litres of municipal household wastewater every day. Dow has been able to cut its freshwater use in half by using the wastewater from the municipality and also through recycling efforts. By managing water in this manner, Dow has also reduced the amount of brackish water required.

Along with significant reductions in the amount of freshwater used by the site, an additional major environmental benefit lies in the fact that the household wastewater can be purified under lower pressure than the salt water that was used in the past. This translates into 65% less energy and 500 tons fewer chemicals to be used per year, and consequently 5,000 tons less CO_2 is discharged annually. As an additional outcome, every litre of water is used three times, instead of once.

The result is a reliable long-term water supply for the site which allows the manufacturing facilities to be cost effective. A key aspect of this project is the partnership between Dow, the water company Evides and the regional Water Board. This partnership allows water to be supplied for the same prices as Dow had paid in the past.

Source: Reproduced from WBCSD (2010).

References

APFAMGS (Andhra Pradesh Farmer Managed Groundwater Systems Project). 2008. Project Completion Report supported by FAO in cooperation with Bharati Integrated Rural Development Society (BIRDS). Andhra Pradesh, APFAMGS.

Baroang, K. M., Hellmuth, M. and Block, P. 2010. *Identifying Uncertainty and Defining Risk in the Context of the WWDR4.* Issues Workshop Discussion Paper prepared for the World Water Assessment Programme (WWAP). New York, Earth Institute, Columbia University, International Research Institute for Climate and Society.

Butler, D. and Memon, F. A. 2006. *Water Demand Management.* London, IWA Publishing.

Cai, X. and Wang, D. 2006. Calibrating holistic water resources-economic models. *Journal of Water Resources Planning and Management,* Vol. 132, No. 6, pp. 414–23.

Crase, L. (ed.) 2008. *Water Policy in Australia: The Impact of Change and Uncertainty.* Washington DC, Resources for the Future. http://admin.cita-aragon.es/pub/documentos/documentos_CRASE_2-5_b8e6f4de.pdf

Draper, A. J., Jenkins, M. W., Kirby, K. W., Lund, J. R. and Howitt, R. E. 2003. Economic-engineering optimization for California water management. *Journal of Water Resources Planning and Management,* Vol. 129, No. 3, pp. 155–64.

DWA (Department of Water Affairs). 1997. *South Africa's White Paper on Water Policy.* Section B (New National Water Policy), sub-section 5.2.2 (Environmental Requirements). Pretoria, Government of South Africa.

EA (UK Environment Agency) 2011. *National Infrastructure Plan – A Vision for Water.* London, EA. http://publications.environment-agency.gov.uk/PDF/GEHO0111BTJC-E-E.pdf

Eichenseher, T. 2010. How to Stem a Global Food Crisis? Store More Water. *National Geographic.* 7 September.

Gill, S., Handley, J. F., Ennos, A. R. and Pauleit, S. 2007. Adapting cities for climate change: the role of the green infrastructure. *Built Environment,* Vol. 33, No. 1, pp. 115–33.

Grossi, P. and TeHennepe, C. 2008. Catastrophe modelling fundamentals. *The Review. A Guide to Catastrophic Modelling.* London, Informa, pp. 6–9.

GWP (Global Water Partnership) Integrated Water Resources Management Toolbox. 2008. *India: Andhra Pradesh Farmer Managed Groundwater System; Demand Side Groundwater Management*. Stockholm, GWP. http://www.gwptoolbox.org/index.php?option=com_case&id=277

Hammer, D. A. 1989. *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural.* Fla., Lewis Publishers.

Hickey, J. and Warner, A. 2005. Sustainable Rivers Project – A Corps and Conservancy Partnership: River project brings together Corps, The Nature Conservancy. *The Corps Environment,* April.

IWMI (International Water Management Institute). 2009. Flexible water storage options and adaptation to climate change. *Water Policy Brief,* 31. Colombo, IWMI. http://www.iwmi.cgiar.org/Publications/Water_Policy_Briefs/PDF/WPB31.pdf

––––. 2010. In a changing climate, erratic rainfall poses growing threat to rural poor, new report says. R&D by EurekAlert. Battaramulla, Sri Lanka, IWMI. http://www.iwmi.cgiar.org/News_Room/pdf/RDMAG-In_a_changing_climate_erratic_rainfall_poses_growing_threat_to_rural_poor.pdf

Jakeman, A. J. and Letcher, R. A. 2003. Integrated assessment and modelling: features, principles and examples for catchment management. *Environmental Modeling Software,* Vol. 18.

Kato, S. and Ahern, J. 2008. Learning by doing: adaptive planning as a strategy to address uncertainty in planning and management. *Journal of Environmental Planning and Management,* Vol. 51, No. 4, pp. 543–59.

Kumar, M. D., Sivamohan, M. V. K., Niranjan, V. and Bassi, N. 2011. *Groundwater Management in Andhra Pradesh: Time to Address Real Issues.* Hyderabad, India, Institute for Resource Analysis and Policy.

Kwadijk, J. C. J., Haasnoot, M., Mulder, P. M., Hoogvliet, M. M. C., Jeuken, A. B. M., van der Krogt, R. A. A., van Oostrom, N. G. C., Schelfhout, H. A., van Velzen, E. H., van Waveren, H. and de Wit, M. J. M. 2010. Using adaptation tipping points to prepare for climate change and sea level rise: A case study in the Netherlands. *Wiley Interdisciplinary Reviews: Climate Change,* Vol. 1, No. 5, pp. 729–40.

Lipkow, U. and von Münch, E. 2009. *Constructed Wetland for a Peri-urban Housing Area Bayawan City, Philippines – Case Study of Sustainable Sanitation Projects.* Sustainable Sanitation Alliance (SuSanA). http://www.susana.org/docs_ccbk/susana_download/2-51-en-susana-cs-philippines-bayawan-constr-wetlands-2009.pdf

Lockwood, M., Worboys, G. and Kothari, A. 2006. *Managing Protected Areas: A Global Guide.* London, Earthscan.

Mangrove Action Project. 2008. *Vietnam's Mangrove Restoration Program.* Port Angeles, Wash., US, Mangrove Action Plan. http://mangroveactionproject.org/news/current_headlines/vietnams-mangrove-restoration-program

Mayer, A. and Muñoz-Hernandez, A. 2009. Integrated water resources models: An assessment of a multidisciplinary tool for sustainable water resources management strategies. Geography Compass, doi:10.1111/j.1749 8198.2009.00239.x

McCartney, M. and Smakhtin, V. 2010. *Water Storage in an Era of Climate Change: Addressing the Challenge of Increasing Rainfall Variability.* Blue Paper. Battaramulla, Sri Lanka, International Water Management Institute (IWMI).

Moore, A. L. and McCarthy, M. A. 2010. On valuing information in adaptive-management models. Conservation Biology, Vol. 24, No. 4, pp. 984–93.

MWP (Mondi Wetlands Programme). N.d. Website. Irene, Pretoria, South Africa, MWP. http://www.wetland.org.za/

New York City. 2009. *NYC Green Infrastructure Plan – A Sustainable Strategy for Clean Waterways.* New York, City of New York.

Panda, S. M. 2007. *Women's Collective Action and Sustainable Water Management: Case of SEWA's Water Campaign in Gujarat, India.* CAPRi Working Paper No. 61. Washington DC, International Food Policy Research Institute (IFPRI).

PEDDR (Partnership for Environment and Disaster Risk Reduction). 2010. *Demonstrating the Role of Ecosystems-based Management for Disaster Risk Reduction.* Background Paper prepared for the ISDR Global Assessment Report on Disaster Risk Reduction 2011. Geneva, UNISDR.

Reij, C., Tappan, G. and Smale, M. 2010. *Resilience to Drought through Agro-ecological Restoration of Drylands, Burkina Faso and Niger.* Case study prepared for the PEDRR Background Paper to the 2011 Global Assessment Report on Disaster Risk Reduction. Geneva, UNISDR.

The Review. 2008. A Guide to Catastrophic Modelling. London, Informa. http://www.rms.com/Publications/RMS%20Guide%202008.pdf

Rosenberg, E. and Taylor, J. 2005. *Mondi Wetlands Project Evaluation. Final Report.* Irene, Pretoria, South Africa, Mondi Wetlands Project (MWP).

Saleth, R. M. and Dinar, A. 2004. *The Institutional Economics of Water: A Cross Country Analysis of Institutions and Performance,* Washington DC, The World Bank.

Samuelson, W. and Zeckhauser, R. 1988. Status quo bias in decision-making. *Journal of Risk and Uncertainty,* Vol. 1, pp. 7–59.

Schuijt, K. 2002. *Land and Water Use of Wetlands in Africa: Economic Values of African Wetlands.* Laxenburg, Austria, International Institute for Applied Systems Analysis. http://www.iiasa.ac.at/Admin/PUB/Documents/IR-02-063.pdf

Shah, H. 2008. Learning lessons from the unexpected. *The Review. A Guide to Catastrophic Modelling.* London, Informa, p. 5.

Shaw, W. D. and Woodward, R. T. 2010. Water management, risk and uncertainty: things we wish we knew in the 21st Century. *Western Economic Forum,* Vol. 9, No. 2, pp. 7–21. http://agecon2.tamu.edu/people/faculty/shaw-douglass/wef.pdf

Souza, S. M. 2006. *Gender, Water And Sanitation: Case Studies on Best Practices* (Advance Version). New York, United Nations. http://www.un.org/esa/sustdev/sdissues/water/casestudies_bestpractices.pdf

UNEP (United Nations Environment Programme). 2002. *New Partnership for Africa's Development (NEPAD) Action Plan for the Environment Initiative.* Midrand, South Africa, NEPAD. http://www.unep.org/roa/Amcen/docs/publications/ActionNepad.pdf

UNISDR (United Nations International Strategy for Disaster Risk Reduction). 2011. *Global Assessment Report on Disaster Risk Reduction.* Geneva, UNISDR.

WBCSD (World Business Council on Sustainable Development). 2010. *The Dow Chemical Company – Utilizing household wastewater in the large-scale.* Geneva, WBCSD. http://www.wbcsd.org/Plugins/DocSearch/details.asp?DocTypeId=24&ObjectId=MzkxMDA&URLBack=%2Ftemplates%2FTemplateWBCSD5%2Flayout%2Easp%3Ftype%3Dp%26MenuId%3DODY%26doOpen%3D1%26ClickMenu%3DRightMenu

Wieder, R. K. 1989. A survey of constructed wetlands for acid coal mine drainage treatment in the eastern United States. *Wetlands,* Vol. 9, No. 2, pp. 299–315.

World Bank. 2010. Deep wells and prudence: towards pragmatic action for addressing groundwater overexploitation in India. *A Groundswell of Change: Potential of Community Groundwater Management in India.* Washington DC, International Bank for Reconstruction and Development/The World Bank, pp. 59–77.

WWF (World Wide Fund for Nature). 2008. *Water for Life: Lessons for Climate Change Adaptation from Better Management of Rivers for People and Nature.* Gland, Switzerland, WWF.

WWF South Africa. n.d. *Mondi Wetlands Programme.* Website. Cape Town, South Africa, WWF Africa. http://www.wwf.org.za/what_we_do/freshwater/mondi_wetlands/

WMO (World Meteorological Organization). 2001. Technical reports. *Hydrology and Water Resources,* No. 73. Geneva, WMO. http://www.wmo.int/pages/prog/hwrp/documents/TD73.pdf

CHAPTER 14

Responses to risks and uncertainties from out of the water box

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As seen in the previous chapter, water managers use a number of mechanisms to help reduce the risks and uncertainties they face. Water policy responses can take various forms, from risk avoidance to anticipatory adaptive management. However, in a world where risk and uncertainties prevail in every domain of human life, responses to water challenges must come primarily as part of attempts to address (or in some cases, failure to address) other sectoral risks and uncertainties.

As noted in WWDR3, many of the problems faced within the water sector are caused by decisions made in other sectors, while many of the solutions to water problems can also be found within these sectors. Most decisions, within or outside the water world, involve some form of risk management. Anticipation of future benefits or threats are an integral part of sectoral decisions and business decisions alike. These decisions do not always take water into consideration, but often have an impact on water – and an impact on the types of decisions and reactions that water managers have to choose from.

This chapter seeks to demonstrate how the management of risks and uncertainties outside of the 'water box' can also have benefits for water management.

14.1 Reducing poverty and greening growth and economies

Water is so close to the heart of social and economic development that it is difficult to address one without addressing the other. Yet short-term plans for poverty reduction and economic development are often undertaken without a long-term analysis of potential water trade-offs, creating unsustainable development pathways.

BOX 14.1

Cuba uses organic agriculture for sustainable growth

The Cuban government responded to a food crisis in September 1993 by eliminating the majority of state farms and turning them into basic units of cooperative production. Much of the 80% of all farmland that was once held by the state was turned over to the workers and re-established as worker-owned enterprises. Although peasants did not own the land, they were allowed to rent the land indefinitely and free of charge as long as they continued to meet production quotas for their key crops.

Food crops produced in excess of these quotas could be freely sold at farmers markets, thereby providing a price incentive for farmers to effectively use new organic technologies such as biofertilizers, earthworms, compost and the integration of grazing animals. Farmers also revived traditional techniques such as intercropping and manuring in order to increase production yields.

Public policies also supported urban organic agriculture through the Programa Nacional de Agricultura Urbana (National Programme of Urban Agriculture) in 1994, which was designed to encourage urban farmers to produce diversified, healthy and fresh products. Havanans transformed their vacant lots and backyards into small farms and grazing areas for animals. This resulted in 350,000 new well-paying jobs (out of a total workforce of 5 million), 4 million tonnes of fruits and vegetables produced annually in Havana (up tenfold in a decade) and a city of 2.2 million agriculturally self-sufficient inhabitants.

While ensuring national food security under a trade embargo, Cuba's transition to organic agriculture has also had a positive impact on people's livelihoods by guaranteeing a steady income for a significant proportion of the population. Moreover, the lack of pesticides for agricultural production is likely to have a positive long-term impact on Cubans' well-being since such chemicals are often associated with various negative health implications such as certain forms of cancer.

Source: Reproduced from UNEP (2011); see also Alvarez et al. (2010).

Beyond the provision of water for basic human needs, such as food, drinking and hygiene, many development efforts have an impact on water risks and uncertainties. In most cases, more development means more water use, and more water pollution arises from higher levels of economic growth. For example, intensification of agricultural production is continuously highlighted as the primary engine for growth and poverty reduction in developing and emerging countries alike. While this is true, it has an impact on the availability of water for other uses. Choosing diverse economic growth pathways could therefore help to address risks and uncertainties related to water availability; however, very few countries have the option to do so because the trade-offs and political costs are so high and immediately felt.

Box 14.1 illustrates how one country, Cuba, has elected to maintain agriculture as an engine of poverty reduction, but has adopted policies to promote organic methods and intensify crop production per hectare, this reducing water pollution and creating improved water use efficiency, with a lesser impact on scarce water resources, thereby reducing risks of future water crises and ensuring a sustainable basis for economic development.

In some cases, green growth entails turning a development challenge – for example, lack of access to chemical fertilizer – into a sustainable development opportunity. Following this model, existing water scarcity could provide a basis for technological innovation to help countries leapfrog towards greener economies, while avoiding the common risks faced by other countries. In countries where expensive water-based sanitation systems are out of reach, especially in rural areas, for example, the dissemination of dry toilets or composting toilets can be an effective alternative, ensuring the provision of basic sanitation services without imposing an additional demand or risk on water. Countries equipped with water efficient or dry devices thereby avoid a series of risks related to water, whether disease-related, scarcity-related or financial in nature.

14.2 Responding to climate change: Adaptation and mitigation

Climate change represents one of the greatest uncertainties currently facing human society. At the global level, there may be a high degree of likelihood for certain types of impact such as temperature increases and sea level rise; however, impacts at the local level are far less predictable.

Efforts are, however, underway to develop adaptation pathways referred to as 'no-regrets' approaches. This means that they will provide benefits – developmental or environmental – regardless of the realization of a given climate scenario. In the absence of certainty regarding local impacts, it is important to plan development in a way that allows for a flexible response to various climate scenarios.

There are also various efforts ongoing throughout the world to anticipate and respond to the impacts of climate change on water, particularly since climate impacts are likely to be felt mostly by increasing uncertainties regarding water availability: changes in rainfall patterns, droughts and so on. As seen in the previous chapter, adaptive management provides a useful framework through which to make various decisions, and with the help of increasingly precise models and data, can help to somewhat reduce uncertainties.

Certain efforts to plan for climate change also provide solutions to water risks and uncertainties without specifically intending to do so. In many countries already suffering from low agricultural yields, for example, efforts to promote no-regrets climate adaptation include measures that combine diversification out of agriculture, sustainable technologies for achieving higher yields per inputs, and technology transfer for the promotion of more sustainable input use (such as land, water, fertilizers, labour). This can have multiple beneficial impacts on mitigating water risks and uncertainties, since it provides the means of producing more food, using theoretically less water. In a context where water is likely to become more scarce, investment in

BOX 14.2

Reducing Emissions from Deforestation and Forest Degradation (REDD) with water co-benefits

The UN-REDD Programme is the United Nations Collaborative initiative on Reducing Emissions from Deforestation and Forest Degradation (REDD) in developing countries. The programme takes as its basis the statement of the Intergovernmental Panel on Climate Change (IPCC) that the forestry sector, mainly through deforestation, accounts for about 17% of global greenhouse emissions, making it the second-largest source of emissions after the energy sector. The basic assumption is that 'reduced deforestation and forest degradation can play a significant role in climate change mitigation and adaptation, yield significant sustainable development benefits, and may generate a new financing stream for sustainable forest management in developing countries. If cost-efficient carbon benefits can be achieved through REDD, increases in atmospheric CO_2 concentrations could be slowed, effectively buying much needed time for countries to move to lower emissions technologies.' (FAO/UNDP/UNEP, 2008*b*, p. 1)

It is recognized that properly managed forests provide a number of non-carbon services. They conserve biodiversity, enhance 'soil and water conditions, help ensure sustained supplies of timber and non-timber forest products and help sustain or improve livelihoods and food security for local communities' (FAO/UNDP/UNEP, 2008*a*). However, there may be trade-offs between forests and water, since site-specific land uses will affect water services differently. For example, forests can sometimes reduce annual water flows, effectively creating a new water risk; however, they can also play a role in reducing sedimentation – in this case reducing risks to a hydropower plant or controlling flood risks. Careful site-specific identification of the water risks and co-benefits expected from a REDD initiative, as well as appropriate ranking of various co-benefits, could prove useful tools in devising appropriate REDD programmes to help mitigate climate change as well as water risks and uncertainties.

Ecuador provides an example of such environmental co-benefits through implementation of its REDD strategy, via the Socio Bosque Programme (an incentive-based policy to tackle deforestation). Throughout the Programme, forest landowners and indigenous communities voluntarily commit to conserving their native forests for a period of 20 years. In exchange, they receive a yearly economic incentive. Since September 2008, Socio Bosque has signed conservation agreements that cover more than 400,000 ha, benefiting more than 40,000 people. The specific identification, ranking and monitoring of co-benefits, both social and environmental (including expected water benefits), occurs through the establishment of a system of safeguards, integrated within the monitoring structure of the REDD programme. This helps to ensure that future risks posed by climate change to water provision, quantity or quality, will be reduced, generating additional adaptive benefits for targeted communities.

Source: World Bank (2011).

agricultural development for climate adaptation can also provide a response to water uncertainties.

An example of efforts creating mutually supporting benefits is the interface between forest management and water resources management (Box 14.2).

14.3 Business decisions to reduce risk and uncertainties

Most business decisions are based on an approach to risks and uncertainties. Decisions on investments and modes of production make presumptions about the future. Many decisions that are uniquely motivated by the financial bottom line can also provide effective means of reducing risks and uncertainties related to water.

These can also be encouraged by government policies such as taxation rates, or fiscal incentives for attracting investment and business in a given location, while legal frameworks also go a long way to reducing uncertainties by providing boundaries and defining incentives for the investment context. It is not rare to see tax benefits offered to companies in exchange for the job

BOX 14.3

Restoring water provision in a dry area: Italcementi

The Sitapuram limestone mine is a captive mechanized open-cast mine operated by Zuari Cement Ltd (part of the Italian Italcementi Group). It is located at Dondapadu, in Nalgonda District, in south-eastern India. The area sustains agriculture while two perennial streams flow through the existing mining lease area and eventually into Dondapadu Village. The area has a tropical climate with an average rainfall of 64 cm, and a maximum humidity of 82%. The temperature ranges from 22 to 50ºC.

The company's objective was to reach the base rock (sandstone) after removing limestone, and convert the excavated area into a lake (75–80% of the mining area) using a geo-hydraulic model for the groundwater balance, then develop a recreation site around it. The company also opted to develop a green belt around the lake to maintain the soil and help protect the flora and fauna.

The conversion of the excavated area into a lake included the creation of small ponds and larger water bodies, in addition to regular assessment of water quality and the water table. Catchment drains or garland drains were constructed and connected to pits to arrest silt and sediment flowing out of the mining area. This helped to reduce uncertainty by creating water reserves and decreased the potential pollution from the mining activities.

The quarry has been operational since 1986, and an adjacent green belt was developed in 2000. Bushes were planted on the slope of the pit to retain soil and protect the pit's walls from collapsing. The developed green belt along the boundary of the mining lease area acted as a barrier, protecting the surrounding area from the dust and noise created by mining activities. In 2007, 300 Ganuga plants were planted near the factory's residential complex. The topsoil removed from the first bench of the mines was used to make a bed above the exposed earth of the land, before plantation. Jatropha plants (for bio-diesel) are being grown on 20 acres in and around the mining lease areas. PVC pipelines were laid to provide a permanent water source to the trees from the quarry bench.

The results have been as follows:

- The creation of a large body of water, which has attracted many birds from other areas, including ducks, cranes and hornbills, and sometimes kingfishers if fish have spawned in water reservoirs. This adds to the preservation of the ecological environment. The reservoir also benefits the local communities who often face water scarcity and can use the reservoir for agricultural irrigation and fish cultivation.
- The recharging of the underlying aquifer, which has raised the water table in the surrounding area and increased vegetation.
- Monitoring and management of silt deposition, which prevents overflow of sediments from the mine area into the surroundings and consequent disturbance of local flora and fauna. Some of the mined pits may fill up over a longer period of time.
- The creation of greenery around mine premises, retention of earth due to the plantation of trees and bushes, and reduction of CO_2 levels in the atmosphere.

Source: WBCSD (n.d.).

and wealth creation they can provide in a city, leading them to establish themselves in locations where they may have impacts on water (near water bodies) or where they can more readily use water. For example (as seen in Chapter 9), governments may facilitate land acquisitions by foreign entities for food or other production, because of the wealth it generates for the country, but may be ignorant of the potential impacts these activities could have on their water resources.

The opposite is also true. Governments may choose to attract investments that provide the highest value for water units, although examples of such types of decision remain unfortunately rare. Box 14.3 illustrates how a business decision, initially motivated by profit and the need to access natural resources for production, has helped to reduce risks and uncertainties related to future water scarcity by providing an additional water reserve for communities and the environment.

Tools such as the proper pricing and valuation of water resources (including charges for water abstraction and wastewater discharges, and transferable water rights) can encourage these sorts of decisions by businesses, particularly when water is a key input in production. They can help to highlight trade-offs, costs and benefits/co-benefits that would otherwise not be apparent to business owners. In a government-led example of this, the provincial government of the Northwest Territories in Canada established a comprehensive framework for water planning that includes a vision and strategy, as well as an action plan for achieving water sustainability goals across all sectors. This also includes research into the various values of water, from market value to ecological services provided by watersheds, as well as cultural values (NWT, 2010).

Risk management is an integral part of business, and as noted by the World Economic Forum (2011), is becoming increasingly necessary as the nature of risks and uncertainties themselves evolve, imposing complex and interconnected considerations on businesses and governments alike today. Whereas industry and businesses learn to deal with uncertainties to protect

BOX 14.4

Implicit valuation reduces business and water risks

Rio Tinto Aluminium's Weipa bauxite-mining operations in Australia have multiple sources of water, each of which has its own associated costs and additional values. The four main sources are:

- Decant water (recycled or reused water) from the tailings dam (where the materials leftover after extracting the mined material are stored. These materials often include muds, leachates, chemical residues, as well as crushed rock).
- Site rainfall runoff captured in 'slots' (like small wells) and other small storage sites across the mining lease.
- Shallow aquifers underlying the area.
- The deeper aquifers of the Great Artesian Basin.

Availability of the different sources can vary during the year, particularly the first two. Rio Tinto identified the level of sensitivity of the shallow aquifers and the Great Artesian Basin during normal environmental risk management processes. This has been reinforced by engagement with key stakeholders, including the Great Artesian Basin Coordinating Committee and non-governmental organizations. The latter have focused on the connectivity that can occur between the shallow aquifers and local rivers.

These processes have aided the establishment of a formal hierarchy of sources, directing the operation to source first from tailings dams, then 'slots', then the shallow aquifers, and finally the Great Artesian Basin aquifers.

In general, the costs associated with sourcing from tailings dams and slots are less than those arising from operating borefields fed by underground aquifers. However, due to the large area of the mining lease, there are situations where it could be both cheaper and more convenient to source from one of the latter.

The establishment of the sourcing hierarchy effectively places an implicit value on the natural sources of water. In the case of the Great Artesian basin, the focus is on the long-term sustainability of the resource, as it has the slowest rate of recharge. The shallow aquifers recharge very quickly due to the climate; their shallow depth, though, can be linked more closely to the river ecosystems.

Source: Reproduced from WBCSD (n.d.).

their investment, governments and communities can apply similar risk management models to protect their own livelihoods, safety and development.

Other factors are also increasingly motivating businesses to take certain types of decisions, in particular related to business or brand image, reputational risk and social responsibility. As noted in a CERES report (2010), license to operate can no longer be taken for granted, as resources become increasingly scarce, and consumers and shareholders demand greater accountability in relation to sustainability and equity standards.

Unfortunately, not all well-intentioned, reputation-based business decisions lead to positive impacts on water. In a recent study, it was noted that 'paper manufactur[ing] … plants that use wastepaper as raw material require more water per ton of paper produced to remove ink, dirt, plastic, and other contaminants from the pulp slurry. Second, reuse of water raises chemical oxygen demand levels in effluent, making wastewater harder to dispose of' (Klop and Wellington, 2008, p. 30). Using recycled material, although 'good' from a public image perspective, can have negative environmental consequences if not undertaken within a full life-cycle overhaul of production processes.

BOX 14.5

Business decision to promote reputational advantage leads to water benefits

Water efficiency has long been an environmental focus at PepsiCo. Through the third quarter of 2010, our global food and beverage businesses reduced water-use intensity by 19.5% versus 2006. And we're on track to achieve our 2015 target for company-owned facilities. Upgrading our facilities with new technologies is one important way we are reaching this goal. For example, our Frito-Lay facility in Casa Grande, Arizona has been equipped with a state-of-the-art water filtration and purification system that can recycle and reuse up to 75% of the water used in production. Similar technology is also being deployed in our Tingalpa facility in Australia, a water-stressed area. …

In 2009, PepsiCo's operations in India achieved positive water balance, enabling us to give back to society more water than we used to manufacture our products. To expand this achievement to other water-distressed areas where we have a presence, we have launched a number of projects. In 2010, for example, we began working with The Nature Conservancy to develop ways to identify areas of high water risk, so we can focus our attention and resources on achieving 'net positive water impact' in the most vulnerable areas where we operate. We have selected watersheds in China, Mexico, Europe, India and the US to pilot the development of a flexible and robust system that allows PepsiCo plants not only to characterize their water risk, but also identify locally relevant restoration initiatives that will improve water availability.

Source: Reproduced from PepsiCo (2011, p. 33).

Box 14.5 illustrates one example of a business decision driven both by the need to address access to key production input and to increase the positive image of the company brand. The PepsiCo 2010 annual report describes various efforts to reduce its environmental footprint, by increasing water-use efficiency and by working with non-governmental organizations (NGOs) (The Nature Conservancy) to implement environmental rehabilitation and conservation efforts.

14.4 Managing sectoral risks to generate benefits to water

In the absence of a comprehensive framework for managing the increasingly complex trade-offs between policy choices, one approach may be to manage sectoral risks in a way that seeks to maximize benefits of water, or that reduces the uncertainties and risks faced by water users. This can reduce the number of variables, drivers and determinants to be considered in a given policy or investment choice, yet help to create win–win situations. The following section provides examples of such win–win situations.

14.4.1 Reducing risks and costs in the transport sector

Building large infrastructure requires a certain degree of forecasting to ensure the viability of investments. Most large-scale projects for transportation now include some mechanism for reducing future uncertainties, particularly as regards climate change, as seen above, but also take into consideration other drivers such as population and consumption patterns.

Box 14.6 illustrates how one company, in an effort to lengthen the durability of its infrastructure investment and reduce maintenance costs, has undertaken measures to reduce damage risks, which have in return had positive impacts on reducing uncertainties regarding future water flows and supply in the surrounding region, with the added benefit of providing developmental and environmental assets.

14.4.2 Reducing health risks includes reducing water risks

Lifestyle choices often have unintended or misunderstood impacts on natural resources. Meat-rich diets, common in developed countries, and on the rise in rapidly emerging countries, are also having an impact on soil, land and water resources.

In a recent article, Capon and Rissel (2010) show the correlation between climate change and chronic disease, with diet as the main factor. Meat-rich diets and low rates of exercise contribute to creating heavy disease burdens and high health costs in many developed countries. There are a number of programmes already underway to promote more active lifestyles and healthier diets, such as the use of public transport. These are noted as having potential for co-benefits in terms of addressing GHG emissions, reducing pollution and promoting healthier lifestyles. They also have significant co-benefits for water, by reducing the use of water consumed as a result of meat consumption, and also by reducing the risk of water pollution from unsustainable or inefficient transport.

In another example, win–win benefits between water and health planning can be found as the world's concern over pandemics and rapidly transmissible animal and human diseases increases. Since water acts as a vector of transmission or as a determining factor in the prevalence of certain transmissible diseases, efforts

BOX 14.6

Autovias's Waterway Program decreased the need for road maintenance while helping to recharge one of Brazil's most important aquifers

Most problems on the planned road occur during the rainy season when water gathers on roads and then runs off, causing erosion and road damage. So Autovias, a company belonging to the Spanish group Obrascon Huarte Lain S.A. (OHL), has developed a project that collects water on the highways' surfaces and directs it towards the Guarani aquifer recharge zone. The company designed the program mainly to protect this vital water resource. Autovias earns no direct income from putting water into the aquifer, but the program helps decrease the need for road maintenance and prevents washouts, thus saving the company money.

Autovias has won a franchise to manage 316.5 km of highways in Brazil's São Paulo State. This involves a number of activities, including infrastructure construction, which often changes the landscape, modifying water dynamics within catchment areas. This can lead to erosion, settling, decreased groundwater infiltration, particularly in aquifer recharge capacity, and direct changes in the local hydrological cycle.

Autovias's environmental commitment to present and future generations is focused on guaranteeing the quality of the hydrological cycle, effectively using and recycling water resources, and developing public awareness of the correct use of water resources.

The Guarani aquifer, the world's largest known aquifer, covers an area of more than 1.2 million km^2 and is under all the highway the company manages. This mega-aquifer extends under Brazil, Paraguay, Uruguay and Argentina. It may contain over 40,000 km^3 of water, which is more than all the water contained in all of the Earth's rivers.

The Waterway Program consists of building rainwater containment dams along the highway grid managed by the company, particularly in the areas of public-supply springs, waterways and headwaters located within the drainage basins of the Sapucaí-Mirim, Pardo and Grande rivers.

Some 520 rainwater containment dams have been built, with an average capacity of 4,000 m^3, making possible a storage capacity of approximately 2 million m^3 of rainwater and rainwater runoff along the toll road network and adjacent areas during the rainy season. The contribution area of the basin extends to approximately 5,200 ha.

These works store rainwater flowing from the highways and adjacent areas; slow the speed of the water, allowing it to recharge the aquifer, and prevent the water table from falling and the ground from eroding and being dislodged along drainage areas.

Source: Reproduced from WBCSD (n.d).

to prevent (or prepare for) global pandemics could generate benefits for managing risks and uncertainties related to water. A World Health Organization (WHO) study revealed that the return on investment from each dollar spent on water and sanitation in developing countries would be between US$5 and US$28 (Hutton and Haller, 2004).

Box 14.7 illustrates how crowd sourcing can provide a tool for reducing risk and uncertainties in various sectors, from crises to pandemics, with side benefits for water management.

14.4.3 Rising risks and uncertainties from the energy sector

A number of international organizations highlight the water-food-energy nexus as illustrating the most difficult choices, risks and uncertainties facing policy-makers today. Examples abound of the various intended or unintended consequences of favouring one pillar over the other (e.g. food security vs. energy security). For example, the International Energy Organization (IEA) predicts that 'at least 5% of global road transport will be powered by biofuel [by 2030] – over 3.2 million barrels per day. However, producing those fuels could consume between 20–100% of the total quantity of water now used worldwide for agriculture' (WEF, 2011, p. 31) if the production processes and technology remain unchanged. Another example is shale gas extraction, which promises access to new reserves of fossil fuels, but is highly water-intensive and may pose a risk to water quality.

A key challenge will therefore be to incorporate the complex interconnections of risks into response

BOX 14.7

Crowd-sourced health information reduces risks and uncertainties for water

In the aftermath of the tsunami in Japan, in 2011, a number of initiatives began gathering information on survivors, radiation levels and rescue efforts. Ushahidi, an international crowd-sourcing platform, helped to establish a site dedicated to mapping danger zones and relocating lost family members. The site enabled anyone with a mobile phone or smartphone to post details of survivors in difficult-to-reach or unsafe areas. This information was then relayed to rescue operations. In turn, the site posted easily accessible information on the nearest emergency services stations, as well as locations of safe water supplies and food stores (Bonner, 2011). Pachube provided another site where real-time radiation readings taken by citizens, combined with official data, were uploaded onto mapping software to provide a tool to help track radiation movements. This also enabled grouped monitoring of tap water quality.

Another application, developed by Google Trends, enabled passive crowd sourcing of health information. Based on a statistical analysis of search words entered in a given location, the service was able to monitor and, in some cases, predict flu outbreaks in the United States of America and Canada with high degrees of accuracy (Google, 2011). Government authorities and water managers could use similar mechanisms to obtain real-time water availability and quality reports. In fact, a number of applications exist today whereby users can upload information on the status of water levels and quality in their area (see CreekWatch).

Berkeley students in India launched the NextDrop project to assist households to predict water availability, providing further proof that crowd sourcing in the health sector can help reduce water uncertainties, including those related to water. 'Information about local piped water deliveries was delivered over cell phones from water utility employees who call an interactive voice response system when they open valves to distribute water. These reports are used to generate real-time water availability updates and notifications 30-60 minutes in advance of water delivery. In addition, NextDrop uses crowd-sourcing to verify the accuracy of utility reports and create a feedback loop, introducing much needed visibility for engineers in the water utility.' (NextDrop, n.d.)

A similar partnership is being entered between Google and UN Habitat in Zanzibar, where partners worked together to establish citizen-based participatory monitoring techniques to support and empower communities in the management of their newly constructed water resources. A system for collection of geo-referenced data, disaggregated by gender and socio-economic group, and supported by information on the health and environmental status was developed. The partnership has also established a system of benchmarking service providers not only to improve service coverage and efficiency, but also to enhance accountability to customers (UN-Habitat, 2010).

Note: For more information on CreekWatch see http://creekwatch.researchlabs.ibm.com/

strategies that are integrated and take into account the many relevant stakeholders.

14.4.4 Win–win reduction of uncertainties through better integrated urban planning

Modelling tools can also help to reduce uncertainties when considering various drivers and policy options.

BOX 14.8

Landscape analysis helps reduce uncertainties within urban planning requirements: The case of Oregon

The development of spatially explicit landscape analyses is a principal activity in research on the relationships between human activities and changes occurring in natural systems. Using geographical information systems and related tools we produced digital and paper representations depicting the past, present, and potential future conditions of a 320 km^2 watershed in western Oregon. These tools were used to identify trends over space and time in human occupancy and natural resources. Based on a set of values and desired future conditions developed by working with citizen groups, digital representations of the alternative future landscapes were evaluated for their effects on water quality and biodiversity using hydrological and ecological effects models. The water quality evaluative model, a non-point pollutant source geographic information system model, simulated storm events based on field data to calculate pollutant loads across the five alternative futures, the present, and the past. The biodiversity evaluative model measured the change in species richness and potential habitat area for breeding species in each alternative future and in the past and compared these data to the present.

Results from the water quality model show increases in the volume of surface water runoff and total suspended solids under the development-oriented futures in catchments undergoing significantly increased residential development or having a high percentage of area in erosive soils on steep slopes. Results from the biodiversity model show that all native species have at least some habitat in all alternative futures. If land use trends in the watershed continue unchanged or become more highly developed, there will be an increased risk to abundance of extant native species. The set of species at risk in the development-oriented futures differs significantly in composition and is placed at risk at a higher rate than in the past, suggesting that the kinds of habitat changes to date differ from those envisioned in the alternative.

Source: Reproduced from Hulse et al. (2000, ©2000 by the Board of Regents of the University of Wisconsin System. Reproduced courtesy of the University of Wisconsin Press.).

Water usually features prominently in urban planning considerations, but the integration of water's various values and uses – and the risks and uncertainties affecting each of these – is rather more recent. Box 14.8 illustrates how a city has undertaken a modelling exercise in order to determine trade-offs, while considering water's various values in the community.

14.5 Mitigating risks and uncertainties

When it is not possible to minimize risks or to reduce uncertainties, it is sometimes possible to minimize the consequences through mechanisms that help share risk burden, or that mitigate the various negative consequences of a given possible outcome. Insurance is of one of the oldest such mechanisms – one that is applicable to all sectors, but that also helps to reduce the impacts of water-related risks. Sharing or redistributing the burden of risk becomes a useful mechanism where the possible consequences of a given risk are heavier for one group as compared to another (for example, the rural poor can withstand less risk than large multinational corporations).

14.5.1 Insurance as a risk minimizing mechanism

There are different ways of sharing risk burden. One such is risk spreading across space (geographic risk spreading), for example, where complementary climate patterns have been identified in different regions. In Africa, for example, a dry season in the eastern region is often associated with a wetter season in the southern region, and vice versa. This observation is linked to the ENSO phenomenon: La Niña events are associated with lower rainfall in eastern Africa and higher rainfall in southern Africa, while during El Niño the reverse pattern is often seen. This could provide a mechanism whereby risks and uncertainties related to precipitation and variability could be shared across borders.

Index-based (or parametric) insurance is also emerging as a potentially powerful tool for risk management in all sectors. This form of insurance is linked to an index or event, such as rainfall, temperature, humidity or crop yields, rather than to the amount of actual loss. Rather than addressing the amount of actual loss, this approach makes the product more attractive and more accessible to developing country clienteles, while remaining a financially viable product for insurance providers.

Box 14.9 illustrates a combination of both mechanisms, where disaster risks and uncertainties are reduced through the application of loss modelling, and where risks are redistributed geographically through pooled purchase of insurance products.

14.5.2 Treaties as a mechanisms for reducing uncertainties

Conflict among natural resource users as well as civil unrest can create pressures on water directly or indirectly. Treaties and agreements have always been mechanisms to reduce uncertainties regarding future safety, provision of services or access to resources. Water treaties or agreements regarding water allocation in shared transboundary basins are multiplying, and are often quoted as having side benefits for reducing other risks, through the establishment of trust-building mechanisms and a certain amount of predictability in stakeholder behaviours.

BOX 14.9

The Caribbean Catastrophe Risk Insurance Facility (CCRIF)

The Caribbean Catastrophe Risk Insurance Facility (CCRIF) is based on geographic risk spreading. The CCRIF is designed to limit the impact of extreme weather events such as hurricanes, severe rainfall events and earthquakes. It provides funds when specific events occur, using parametric formulas.

With original funding from the Japanese government, CCRIF has been recapitalized through a multi-donor trust fund and maintained by membership fees paid by the 16 participating governments: Anguilla, Antigua and Barbuda, Bahamas, Barbados, Belize, Bermuda, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago and Turks and Caicos Islands.

Participating countries pool their country-specific risks into one, diversified insurance portfolio. As natural disaster risks in any given year are randomly distributed among the Caribbean islands, the cost of coverage for the pooled portfolio is less than the sum of premiums that the countries would have to pay individually for the same coverage. In practice, insurance premiums are reduced by almost half.

The CCRIF also uses a catastrophe modelling approach (see Chapter 13) as a means of understanding the scope of potential losses from a given risk, and therefore as a basis for pricing insurance premiums for a given territory.

Source: CCRIF (2011).

> "There are different ways of sharing risk burden. One such is risk spreading across space (geographic risk spreading)."

As noted by Dreischova et al. (2001), uncertainties related to water are not always fully recognized in treaty design or in the elaboration of water collaboration mechanisms. The adoption of open-ended strategies, allowing for flexible rule-making within the agreements, indicates a growing understanding of how uncertainties may affect water policy-making. Examples such as the Nile Basin Initiative and the SADC protocol on Shared Watercourse Systems provide mechanisms for managing risks, deciding on allocations and promoting the application of joint norms.

The opposite is also true: agreements and treaties signed for purposes other than water may help reduce risks and uncertainties regarding water, particularly where they provide mutual assurance of the other party's behaviour regarding natural resource use. Peace treaties could be the first mechanism where water risks (at least those that arise from human use) are reduced.

Trade agreements are often cited as having potentially negative consequences, or creating additional risks, for water. The case of the influence of free trade agreements on North American water resources constitutes one such example. Even prior to the signing of the North American Free Trade Agreement (NAFTA), there was debate as to whether or not bulk water exports from water-rich Canada could be pursued or allowed under the current regulatory framework. These fears have heightened since the adoption of NAFTA, specifically 'over whether surface and ground water in its natural state (for example, in lakes and rivers) is subject to NAFTA obligations. Some argue that this is the case. At the same time, however, the governments of Canada, the United States and Mexico have expressly stated that the NAFTA does not apply to water in its natural state' (Johansen, 2002, p. 19).

14.5.3 Addressing water and security concerns through multi-sectoral cooperation

Uncertainties continue to grow, whether related to climate change and resource scarcity or to economic volatility, and security concerns remain at the forefront of policy-making everywhere. In this context, water constitutes a nexus of risk where all these issues mesh, sometimes with dire consequences.

For example, the recent severe drought in East Africa, combined with ongoing conflict in Somalia and Sudan, has resulted in highly volatile conditions where violence and famine are affecting millions of people, already among the poorest in the world. Water scarcity, which has led to crop and livestock failure, has led to migration and increased competition for resources. In a situation where conflict was already rampant and weapons were already available, this has degenerated into widespread humanitarian disaster.

Creating conditions for national and regional security can also generate multiple benefits for water – and become a mechanism for dealing with future water risks and uncertainties. Much has already been said about the potential role of water cooperation in creating the conditions for peace-building across borders, namely by creating conditions of trust, joint objectives and institutions, and gradual achievements that can later translate into broader cooperation.

However the opposite is also true. Cooperation on security issues can help to address water concerns, and thereby help to create conditions for development and growth on all sides. This was recently recognized by the Organization for Security in Central Europe (OSCE), which works to establish regional cooperation frameworks among countries of Central Asia around water (surface and groundwater) management (Box 14.10).

The role of water as a potential factor of stability in war-torn countries or in countries recovering from conflict was also raised in a recent US study on Afghanistan. The study recommended that reconstruction efforts focus on creating institutions with the capacity to withstand and manage shocks and risks, as well as on the need to institute more effective water management systems, both nationally and regionally (US Senate, 2011).

BOX 14.10

Creating cooperative security-based institutions around water in Central Asia

[The OSCE has worked with Kyrgystan and Kazakhstan] in operationalizing the Agreement on Utilization of the Water Facilities of Interstate Use on the Chu and Talas Rivers. As a result, the inter-state Commission was established and the OSCE assisted in … [setting up the Commission and in performing some repair and maintenance works on] multi-purpose water facilities. This framework included mediation to reach consensus between the governments of both countries.

The OSCE also continues to support the Interstate Committee for Water Coordination (ICWC) in Central Asia … with a strong emphasis on regional co-operation, promotion of policies on water management and environmental sustainability in the region. In collaboration with the ICWC, the OSCE is working on seminars to improve the economic mechanisms related to water management and improve environmental conditions to promote co-operation in the region.

Closer interaction between the countries on the sustainable management of water and water related ecosystems is key to ensuring security and development in the region.

Source: Reproduced from OSCE (n.d.).

Conclusion

This chapter highlights how methods used to deal with risks and uncertainties in all areas of socio-economic development can positively or negatively affect water risks and uncertainties, leading to potential restrictions or an increase in the management choices available to water managers. Risk management, whether it takes the form of avoidance, reduction or mitigation, forms an integral part of all policy-making. Moreover, the complexity of the risks and uncertainties now facing society is increasing and accelerating.

Understanding the way choices impact on water can help to shape decisions that maximize benefits in all domains, creating long-term safer and more sustainable pathways for development. This also requires a clear-minded consideration of immediate, mid-term and long-term trade-offs.

References

Alvarez, M., Bourque, M., Funes, F., Martin, L., Nova, A. and Rosset, P. 2010. *Surviving crisis in Cuba: the second agrarian reform and sustainable agriculture.* P. Rosset, R. Patel and M. Courville (eds). 2006. *Promised Land: Competing Visions of Agrarian Reform. Institute for Food and Development Policy.* Oakland, Calif., FoodFirst. http://www.foodfirst.org/files/bookstore/pdf/promisedland/12.pdf

Bonner, S. 2011. RDTN.org: *Crowdsourcing and Mapping Radiation Levels.* Blog entry posted to boingboing, 19 March 2011. http://boingboing.net/2011/03/19/rdntorg-collects-cro.html

Capon, A. G. and Rissel, C. E. 2010. Erratum to: Chronic disease and climate change: understanding co-benefits and their policy implications. *New South Wales Public Health Bulletin,* Vol. 21, No. 10, p. 196.

CCRIF (The Caribbean Catastrophe Risk Insurance Facility). 2011. Website home page and Q&A document. http://WWW.CCRIF.ORG/content/about-us and http://www.ccrif.org/sites/default/files/publications/BookletQuestionsAnswersMarch2010.pdf (Accessed 4 November 2011.)

CERES. 2010. *The 21st Century Corporation: The CERES roadmap for sustainability.* Boston, CERES. http://docs.google.com/viewer?url=http://www.ceres.org/resources/reports/ceres-roadmap-to-sustainability-2010&chrome=true (Accessed 19 October 2011.)

Dreischova, A., Fischhendler, I. and Giordano, M. 2011. The role of uncertainties in the design of international water treaties: an historical perspective, *Climatic Change,* Vol. 105, pp. 387–408.

FAO (Food and Agriculture Organization of the United Nations)/UNDP (United Nations Development Programme/UNEP (United Nations Environment Programme). 2008*a*. *UN-REDD Programme Framework Document.* Geneva, FAO/UNDP/UNEP.

––––. 2008*b*. *Role of Satellite Remote Sensing in REDD.* Issues Paper. Geneva, FAO/UNDP/UNEP. http://www.un-redd.org/LinkClick.aspx?fileticket=p7Ss-fE7AR0%3D&tabid=587&language=en-US

Google. 2011. *Google.org Flu Trends* website. Calif., Google. http://www.google.org/flutrends/ca/#CA

Hulse, D., Eilers, J., Freemark, K., Hummon, C. and White, D. 2000. Planning alternative future landscapes in Oregon: evaluating effects on water quality and biodiversity. *Landscape Journal,* Vol. 19, NO, 1&2, pp. 1–19.

Hutton, G. and Haller, L. 2004. *Evaluation of the Costs and Benefits of Water and Sanitation Improvements at the Global Level.* Geneva, WHO. http://www.who.int/water_sanitation_health/wsh0404.pdf

Johansen, D. 2002. *Bulk Water Removals, Water Exports and the NAFTA.* Ottawa, Government of Canada, Law and Government Division. http://dsp-psd.pwgsc.gc.ca/Collection-R/LoPBdP/BP/prb0041-e.htm

Klop, P. and Wellington, F. 2008. *Watching Water: A Guide to Evaluating Corporate Risks in a Thirsty World.* New York, JP Morgan Global Equity Research. http://www.questwatersolutions.com/Quest%20Water%20Solutions%20Inc./News_files/JPMorgan-WatchingWater-April%202008.pdf

NextDrop. n.d. Website. A collaboration of UC Berkeley School of Information, Department of Civil and Environmental Engineering, and Goldman School of Public Policy. http://www.nextdrop.org

NWT (Northwest Territories). 2010. *Northern Voices, Northern Waters. NWT Water Stewardship Strategy.* Yellowknife, Canada, Department of Environment and Natural Resources (GNWT). http://www.enr.gov.nt.ca/_live/documents/content/NWT_Water_Stewardship_Strategy.pdf

OSCE (Organization for Security and Co-operation in Europe). Website. Vienna, OSCE. http://www.osce.org/eea/45910 (Accessed 4 November 2010.)

PepsiCo. 2011. *Annual Report 2010: Performance with Purpose. The Promise of PepsiCo.* Purchase, NY, PepsiCo. http://www.pepsico.com/annual10/performance/performance.html?nav=environmental

UNEP (United Nations Environment Programme). 2011. *Green Economy Report.* Nairobi, UNEP. http://www.unep.org/greeneconomy/SuccessStories/OrganicAgricultureinCuba/tabid/29890/Default.aspx

UN-Habitat. 2010. *Google and UN-HABITAT Partnership to Improve Data Collection.* UN-Habitat website. Nairobi, UN-Habitat. http://www.unhabitat.org/content.asp?cid=7751&catid=460&typeid=6

US Senate. 2011. *Avoiding Water Wars: Water Scarcity and Central Asia's Growing Importance for Stability in Afghanistan and Pakistan.* A majority staff report prepared for the use of the Committee on Foreign Relations, United States Senate, 112th Congress, first session 22 February 2011.

WBCSD (World Business Council for Sustainable Development). n.d.Website. Repository of Case Studies. Geneva, WBCSD, http://www.fundacionentorno.org/Data/Documentos/Sustain30_090908_proof2173545873.pdf (Accessed 17 October 2011.)

WEF (World Economic Forum). 2011. *Global Risk 2011, Sixth Edition: An initiative of the Risk Response Network.* Geneva, WEF.

World Bank. 2011. *Estimating the Opportunity Costs of REDD+: A Training Manual.* Washington DC, The World Bank Institute/Forest Carbon Partnership Facility. http://wbi.worldbank.org/wbi/Data/wbi/wbicms/files/drupal-acquia/wbi/OppCostsREDD+manual.pdf

CONCLUSIONS

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This fourth edition of the *World Water Development Report* (WWDR4) report has sought to demonstrate the challenges facing water today and the increasing complexity, uncertainties and risks of tomorrow, as well as to provide avenues for responding to these challenges in the near future. Water is at the centre of the development nexus, and it has far reaching connections with every realm of human life – from the basic concerns of food, health and energy, beyond to industry, trade and the economy. Today most of these sectors face a crisis. New approaches that will provide insight into possible futures – and where responses can set the stage for future prosperity and avoid imminent catastrophe – are called for. The WWDR4 reveals that the path to solving these crises flows through water, and that solving water problems now is necessary to ensuring chances for the future of our planet and the prosperity of its people.

Sadly, not much has changed since the publication of the last WWDR in 2009. Nearly 1 billion people still do not have access to improved sources of drinking water and there are more people without access to tap water in cities today than there were at the end of the 1990s. In addition, 1.4 billion people do not have electricity in their homes, and nearly 1 billion suffer from malnutrition. Although there has been progress in achieving some of the water-related Millennium Development Goals (MDGs) in certain countries and regions, much work remains, particularly to address the special needs of the most vulnerable members of society – women and children – who bear the brunt of poverty worldwide.

Water constraints on sustainable development have created hotspots where multiple challenges mesh and result in a spiral of increasing poverty, uncertainty and instability. This happens in all regions, though the root of the challenges may differ from one region to the next. In Africa there is insufficient investment in water infrastructure and accessibility, compounded by low levels of technical and institutional capacity, over-consumption and pollution, which creates increasing constraints on North African countries' economies. In Asia, growing population and urbanization create challenges for sanitation, and disputes between users as well as high exposure to natural disasters and extreme events exacerbate existing vulnerability, risk and uncertainty. Demand is ever-increasing within some Arab and Western Asian countries that are already facing severe scarcity constraints, and in Latin America and the Caribbean, increased demand fuelled by industry, trade and growing economies is also posing a challenge alongside governance systems that are often inadequate to deal with the pressures.

From a sectoral perspective, pressures on water continue to grow and technological innovation that could provide much needed water savings is still not fully implemented. Agriculture, the largest water user, continues to be practiced in a water-inefficient manner in many countries; in developing countries, this is mostly due to a lack of capacity or political support. Higher per capita rates of energy consumption and rapidly growing energy demand are also exerting increased pressure on water, with water-intensive energy sources still being the chief part of the energy portfolio in the vast majority of countries. Great quantities of freshwater are used for urban sanitation (in cities where sanitation services are available), and demands for freshwater are increasing to meet MDG target 7c. The vast majority of wastewater is returned to the environment without treatment, generating health risks to humans and ecosystems.

As was discussed in Chapter 2, water demand is affected by a number of drivers, and while there is uncertainty about how each of these will evolve in future, it is somewhat certain that demand will increase – the big questions remaining, 'Where?' and 'By how much?' It is also somewhat certain that, all other things remaining equal, if our approaches to management remain the same, and if our development trajectories continue without some interjection that alters their course, water resources will be insufficient to meet all future demands. In fact, in many regions and countries that are facing scarcity today (Chapter 7).

As described throughout Part 2 of this report, the world is changing faster than ever and becoming more and more complex. Uncertainties about water availability and demand are increasing, as are the associated risks to development and well-being of people, societies and the environment. Unless we can generate the awareness and political will to react now, the crises we are experiencing now are likely to escalate and the odds of meeting our developmental goals will degenerate. However, the harsh realities of existing challenges outlined throughout the WWDR4 must not completely overshadow important progress achieved since WWDR3.

There is in fact increasing recognition of the link between water and other aspects of development, as exemplified by the Conference on the Water, Energy and Food Security Nexus (Bonn, November 2011). The increasing recognition can be seen as a positive development for water, especially as some of the most prominent initiatives have been led by actors from the energy and food sector, and may be viewed as increased recognition of water's importance in development. Without fully implemented (and adaptable) plans for integrated water resources management (IWRM), the 'nexus' dialogue creates a pragmatic and substantial opportunity for informed decision-making outside the 'water box'. There have been improvements in IWRM as well: preliminary findings from a 2011 UN-Water global survey to determine progress towards IWRM show a wider adoption of integrated approaches with significant impact on development and water management practices at a country level (Chapter 1). There have also been some advances made under the recent United Nations Framework Convention on Climate Change (UNFCCC) Conferences of the Parties (COPs) (Chapter 1).

Unfortunately, while many stakeholders recognize in theory that water is a fundamental aspect of achieving global goals, many such as the MDGs and other international and national processes continue to treat water concerns as separate from other issues and challenges; as do for example climate change negotiations and the UNCSD 2012 (Rio+20) process. Yet as seen in this report, failure to address water concerns creates untenable risks and uncertainties for all developmental sectors –agriculture, energy, industry, health and livelihoods – with consequences for global trade and economic growth.

Water policy-makers and resource managers are beginning to understand that long-term cross-sectoral action is required to manage the resource appropriately. Policy-makers in other sectors also need to see the benefits of rallying to this position, and they need to participate in an integrated approach to addressing multiple sector challenges, managing inter-related risks and reducing uncertainties. Governments and water managers have a responsibility to work with stakeholders and water users in making decisions about re-allocating water to the most appropriate and equitable uses for achieving national development goals. But, as water-related problems extend beyond national boundaries into all spheres of the global economy, concerned national governments – as it is the national governments that drive the international policy – have a responsibility to bring water issues forward on the international stage, so that common problems can find shared solutions.

As noted in Chapter 5, 'water is a fugitive resource', and its role in the global economy is ubiquitous but difficult to grasp. If we continue to ignore its fundamental roles and values (and to underestimate the value of its many benefits) in everyday decisions, at all levels, we will have exhausted the resource's full potential before we can adopt alternate behaviours. Water managers need to take a pro-active leadership role in educating and informing decision-makers in all sectors about the different values of water, its multiple benefits to development, and about the options that can help maximize co-benefits for human socio-economic well-being through water, thereby effectively minimizing potentially negative trade-offs. These win–win approaches abound, as can be seen from the examples in Chapters 13 and 14, and many tools exist for sectoral management – adaptive management, science-based tools, economic approaches and other policy mechanisms – to help deliver multiple benefits.

Managing water in a context of increasing and increasingly complex uncertainty requires new approaches that function across sectoral and institutional boundaries to create new coalitions among water users and providers. Such management approaches are already underway in many contexts, and many countries have experience to showcase. Transboundary watershed management, multi-disciplinary scenario-based planning, and 'green accounting' mechanisms are currently being implemented in developed as well as developing countries. However, broader improvement will require institutions to evolve into more flexible dialogue-based mechanisms that promote continuous discussion on social goals and targets and that provide support for rapid decision-making on water allocation and management in response to rapidly changing circumstances.

Successful water management will also require an explicit recognition of the economic values of water and its different benefits, as seen in Chapter 10, not only because there is a need to promote investment in water infrastructure and institutions, but because without such investment, water will become the 'ghost in the machine': the current economic model encourages investment based on growth scenarios that themselves are based on implicit assumptions regarding natural resources (chiefly water). Failure to understand the way water underpins today's global and local economy will simply lead to unrealistic predictions about sustainable growth. Recognizing the full value of water and its benefits and ensuring these benefits' equitable distribution as well as operational continuity in water services, can help mitigate future economic risks and uncertainties.

Beyond this recognition, successful water management will also require increased investment by national governments and the international community if we are to achieve national and international development goals. Successful management entails both 'hard' investment in solid and lasting infrastructure to provide water services over the long term – thus reducing risk – and 'soft' investment in capacity, science, data collection and analysis, and information about water, so that uncertainties are continuously reduced. It will also require investment in alternative and innovative forms of water service provision, including the restoration of water services provided by healthy ecosystems, which have thus far been largely ignored as entry points for water management. As seen in Chapters 5, 8 and 11, combining hard and soft approaches helps ensure higher degrees of water availability and quality in a sustainable manner.

The optimization and equitable distribution of water's benefits can only occur if economic policy, industrial planning, urban design, food, energy and trade policies become more water conscious. Trade-offs and co-benefits can become more visible thanks to emerging planning tools such as modelling, risk management, low- and no-regrets planning tools (Chapter 8). This helps reduce uncertainties related to water as well as economic uncertainties and risks, and can contribute to higher rates of economic growth. Public and private sector decision-makers can take advantage of a certain degree of public awareness regarding environmental sustainability to make decisions that would perhaps have been harder to make 20 years ago. This growing awareness indicates a willingness on the part of the public to shoulder part of the short-term risk to reduce longer-term uncertainties (social risk tolerance, Chapter 11).

As a risk-taker, the private sector is often the root of technological innovation. In this regard, the push to achieve financial profit can become a useful impetus for water sustainable futures, if harnessed appropriately, motivating technological progress towards more resource efficiency, less waste, and less pollution. Many businesses are in fact one step ahead of governments, by acting on a recognition that, in the long term, environmental sustainability or water stewardship is a prerequisite to economic sustainability. Indeed, in some cases, large private sector firms have shown an eagerness to respond to the market's appetite for corporate responsibility by investing in ecological stewardship which, in exchange, provides them with efficient and continued access to resources. However, this type of approach is not yet part of the mainstream of private sector decision-making, mainly because public policy is lagging behind, and because there remain financial obstacles to the adoption of 'greener' technologies. In contrast, some of these green approaches, while well-intentioned, can have negative consequences for water, as seen for example in Chapter 13.

Hence it is important for governments to send the right signals and provide the right incentives to private sector decision-makers about the hierarchy of trade-offs, and particularly about the place of water in business decisions. Civil society, environmental NGOs in particular, also has a role to play. Where environmental NGOs were once sometimes seen as a force of opposition, their constructive participation in collaborative decision-making today helps ensure that different concerns and interests are appropriately represented in the spectrum of decisions taken by public and private operators.

Anticipating and proactively adapting to change present unique opportunities to bring into effect beneficial change without taking overstated risks. Recognizing that past experience is no longer the best way to anticipate the future (Chapter 8), we can however anticipate outcomes based on current trends. As seen in Chapter 9, analysis of the evolution of key drivers provides useful insights into what might happen if we do nothing, or what could happen if certain decisions were made today. Seeing the world in terms of possible futures can help guide our course from the present moment. Approaches to climate change adaptation provide us with a useful model for 'no-regrets' development planning, in that the model demonstrates how – within a more or less broad window of uncertainty (or certainty) – decisions can be made that achieve maximum benefits regardless of the situation (Chapter 13). Adaptive management and no-regrets planning can be applied to all sectors provided that public and private institutions are given the flexibility (and legitimacy) for course correction when new information is made available to them. As noted earlier and in Chapters 5 and 11, an adaptive approach to IWRM has become increasingly relevant to water and non-water managers alike.

Parallel to this change in how we plan for the future, we also need to significantly invest in our knowledge and understanding of how systems work. Climate predictions, modelling and scenarios should become essential parts of the public policy tool box. Similar knowledge should evolve about water systems in and of themselves, for example groundwater (Chapter 3), or the role of ecosystems in maintaining and regulating water flows and their ability to sustainably provide a wide range of services (Chapters 4 and 8). This knowledge must become an intrinsic part of everyday decision-making, rather than the exclusive domain of water scientists, and must be communicated effectively to a broader range of direct and indirect water users. Knowledge and technological innovation can play a significant role in reducing risks and uncertainties related to water, and in moving us from a water-intensive to a water-efficient development model. As described in Chapter 6, the absence of systematic data collection in most countries impedes regular reporting on water resources and water use situation and trends. There is consequently a growing interest in and demand for better water data and accounting, which needs to be translated into improved data availability, more structured data acquisition, and better information about water – from which different users can calculate indicators of specific interest to them.

The difficulty faced today is in identifying the trade-offs made in everyday policy-making and business. Each decision made has potentially far reaching consequences on water; for example, the recent decision made by certain governments to move away from nuclear energy could have impacts on water use if it leads to water-intensive energy production (for example, oil sands extraction). Hastily made decisions in reaction to catastrophe or perceived public opinion could leave unwanted legacies if they are not considered from a cross-sectoral, long-term perspective. Identifying the 'end-point' or the most preferred outcome (or future) – expressing a vision of a desired future – can help in identifying the acceptable trade-offs in the short, medium and long terms. Yet there is much room for improvement in terms of applying this sort of visioning exercise – whether for water specifically or for development in general. While the MDGs express this sort of vision, by missing the opportunity to explicitly incorporate the cross-cutting nature of water in the development nexus, they may have taken an overly fragmented approach.

There is therefore a need to replace the old ways of sector-based decision-making with a wider framework that considers the multiple facets of the development nexus, and the multiple risks and uncertainties, costs and benefits or every decision, in light of a long-term goal. In this regard, national governments have a major contribution to make by creating stronger, more collaborative, flexible institutions, by adopting appropriate financing mechanisms to ensure the long-term viability of water services and infrastructure, and by ensuring that water considerations are mainstreamed into everyday policy decisions as well as international governance processes. Water managers have a responsibility to continuously inform these processes and to raise awareness of the centrality of water in the development nexus.

This is why the most recent economic crisis could be seen as an opportunity; it provides an occasion for reflecting on a desired collective future, and it provides a critical glimpse of the interconnections between countries, sectors and policies. Similarly, looking at the future through a water lens also provides the insight needed to make decisions that maximize benefits to people, the environment and the global economy.

The financial, food, fuel and climate crises are, even individually, serious problems, but in combination their effects could be catastrophic for global sustainability. The WWDR4 has sought to provide a new way of looking at our water reality, through the perspective of risk and uncertainty. It has sought to encourage different ways of thinking about the world's collective future by identifying tools and approaches that maximize water's benefits to different developmental sectors and by demonstrating that win–win scenarios are indeed possible. Political and business leaders as well as water managers, water users and ordinary citizens have a unique opportunity to see past immediate challenges and risks and to effect long-term change towards sustainable prosperity for all, through water.

BOXES, TABLES, FIGURES AND MAPS

BOXES

TABLES

FIGURES

MAPS

ABBREVIATIONS AND ACRONYMS

AASB	Auditing and Assurance Standards Board (Australia)
AC	Albufeira Convention (Portugal)
ACCA	Association of Chartered Certified Accountants (UK)
ACCRA	African Climate Change Resilience Alliance
ACMAD	African Centre for Meteorological Applications for Development
ACWUA	Arab Countries Water Utilities Association
ADB	The Asian Development Bank
ADPC	Asian Disaster Preparedness Centre
ADSS	advanced decision support system
AfDB	The African Development Bank
AFED	Arab Forum for Environment and Development
AI	Aridity Index
AICD	Africa Infrastructure Country Diagnostic
AMCOW	African Ministers' Council on Water
AMO	Atlantic Multidecadal Oscillation
AMOC	Atlantic Meridional Overturning Circulation
AMWC	Arab Ministerial Water Council
ANA	National Water Agency (Brazil)
AO	Arctic Oscillation
APFAMGS	Andhra Pradesh Farmers Ground Water Management System
APWF	Asia-Pacific Water Forum
ARH	Administração da Região Hidrográfica (Portugal)
ARPA	Regional Agency for Environmental Protection (Italy)
ASCE	American Society of Civil Engineers
ASEAN	Association of Southeast Asian Nations
ATP	adaptation tipping point
AWB	area water board
AWC	Arab Water Council
AWDR	African Water Development Report
AWF	African Water Facility
AWICH	African Water Information Clearing House
AWM	adaptive water management
AWM	agricultural water management
AWTF	Africa Water Task Force
BAT	best available technique
BAU	business as usual
BEP	best environmental practice
BGR	Federal Institute for Geosciences and Natural Resources (Germany)
BIRDS	Bharati Integrated Rural Development Society
BMAP	basin management action plan
BMWS	barley, maize, wheat and soybean
BOD	biological (or biochemical) oxygen demand
BOT	build-operate-transfer
BRIC(S)	countries: Brazil, Russian Federation, India, China (South Africa)
BSE	bovine spongiform encephalopathy
BSR	business for social responsibility
CAD	Central Apennines District
CADA	Central Apennines District Authority
CADC	Commission for the Application and Development of the Convention (Portugal)
CAMRE	Council of Arab Ministers Responsible for the Environment
CAP	Common Agricultural Policy (EU)
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Costa Rica)
CBD	Convention on Biological Diversity
CBO	community-based organization
CBRN	chemical, biological, radiological and nuclear
CBSR	Canadian Business for Social Responsibility
CCAI	International Climate Change Adaptation Initiative
CCRIF	Caribbean Catastrophe Risk Insurance Facility
CD	capacity development
CDA	Chilika Development Authority (India)
CEC	California Energy Commission
CEC	Commission for Environmental Cooperation of North America
CEDARE	Center for Environment and Development for the Arab Region and Europe
CEDAW	Convention on the Elimination of All Forms of Discrimination against Women (UN)
CEH	Centre for Ecology and Hydrology (UK)
CELADE	Latin America and the Caribbean Demographic Centre
CEPMLP	Centre for Energy, Petroleum and Mineral Law and Policy (The University of Dundee)
CHRAJ	Commission for Human Rights and Administrative Justice (Ghana)
CIDA	Canadian International Development Agency
CIF	climate investment fund
CIFOR	Center for International Forestry Research
CILSS	Committee for Drought Control in the Sahel
CIS	Common Implementation Strategy (EU)
CLIMPAG	climate impact on agriculture
CNE	Comisión Nacional de Prevención de Riesgos y Atención de Emergencias (Mexico)
COD	chemical oxygen demand
CONAGUA	National Water Commission (Mexico)
CoP	community-of-practice
COP	Conference of the Parties
CPA	cleaner production assessment
CPWC	Co-operative Programme on Water and Climate (UNESCO-IHE)
CRED	Centre for Research on the Epidemiology of Disasters, Catholic University of Louvain
CRM	climate risk management
CSDRM	climate smart disaster risk management
CSE	Centre for Science and Environment (New Delhi)
CSEC	Supreme Council for Water and Climate (Morocco)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CSR	corporate social responsibility
CVI	Climate Variability Index
CWA	Clean Water Act (USA)

CWPP	Congo Cross-Border Water Pipeline Project
CWSA	Community Water and Sanitation Agency (Ghana)
DAC	Development Assistance Committee (OECD)
DBOT	design-build-operate-transfer
DEWATS	decentralized wastewater treatment systems
DFE	design for environment
DFID	Department for International Development (UK)
DLDD	desertification, land degradation and drought
DO	dissolved oxygen
DOE	US Department of Energy
DPSEEA	driver, pressure, state, exposure, effect and action model (WHO)
DRI	Disaster Risk Index
DRM	disaster risk management
DRR	disaster risk reduction
DWA	Department of Water Affairs (South Africa)
DWAF	Department of Water Affairs and Forestry (South Africa)
EAWAG	Swiss Federal Institute for Aquatic Science and Technology
EC	European Commission
EC-IFAS	Executive Committee of the International Fund for saving the Aral Sea
ECOWAS	Economic Community Of West African States
EDC	endocrine disruptive compound
EEA	European Environment Agency
EHP	Environmental Health Project
EIA	US Energy Information Administration
EMA	environmental management accounting
EMCA	Environment Management and Coordination Act (Kenya)
EMS	environmental management system
ENERGIA	International Network on Gender and Sustainable Energy
ENSO	El Niño-Southern Oscillation
EPA	US Environmental Protection Agency
EPRI	Electric Power Research Institute (USA)
EU	European Union
EUWI	European Water Initiative
EWP	Ecosystem Workforce Program (University of Oregon)
EWRA	Egyptian Water Regulatory Agency
FAO	Food and Agriculture Organization of the United Nations
FIRM	Forum for Integrated Resource Management
FMMP	Flood Mitigation and Management Programme (of the Mekong River)
FO	farmer organization
FONAFIFO	Fondo Nacional de Financiamiento Forestal (Mexico)
FONAG	Water Protection Fund (Ecuador)
FWRA	Florida Water Resources Act
GAR	Global Assessment Report
GAR	groundwater recharge
GAS	Guaraní Aquifer System
GCC	Gulf Cooperation Council
GCF	Green Climate Fund (UNFCCC)
GCM	general circulation model
GDP	Gross Domestic Product
GEF	Global Environment Facility
GEMS	Global Environment Monitoring System
GEO	Global Environment Outlook
GHG	greenhouse gas
GIF	global impact factor
GLAAS	Global Analysis and Assessment of Sanitation and Drinking-Water (WHO/UN-Water)
GLIMS	Global Land Ice Measurements from Space
GLOF	glacial lake outburst flood
GLOWS	Global Water for Sustainability Program
GPOBA	Global Partnership on Output-Based Aid
GPWAR	General Purpose Water Accounting Report
GRACE	Gravity Recovery and Climate Experiment
GTN-H	Global Terrestrial Network for Hydrology
GVEP	Global Village Energy Partnership International
GWC	green water credit
GWCL	Ghana Water Company Limited
GWD	Groundwater Directive (EU)
GWI	Global Water Intelligence
GWP	Global Water Partnership (CACENA, Caucasus and Central Asia; SEA, Southeast Asia)
GWSP	Global Water Systems Project
HAB	harmful algal bloom
HDI	Human Development Index
HEPP	hydroelectric power plant
HIA	Health Impact Assessment
HKJ	The Hashemite Kingdom of Jordan
HRC	Human Rights Council (UN)
HRHR	high risk-high reward
HVBWSHE	Human Values-Based approach to Water, Sanitation and Hygiene promotion
IAHS	International Association of Hydrological Sciences
IBNET	International Benchmarking Network for Water and Sanitation Utilities
IBRD	International Bank for Reconstruction and Development
IBWT	Inter-Basin Water Transfer Project
ICA	Infrastructure Consortium for Africa
ICCPR	International Covenant on Civil and Political Rights
ICE	Instituto Costarricense de Electricidad (Mexico)
ICID	International Commission on Irrigation and Drainage
ICIMOD	International Centre for Integrated Mountain Development
ICLEI	International Council for Local Environmental Initiatives
ICOLD	International Commission on Large Dams
ICPAC	Climate Prediction and Applications Centre (IGAD, Africa)
ICPDR	International Commission for the Protection of the Danube River
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICS	information and communication systems
ICT	information communication technology
IDB	The Inter-American Development Bank
IDRC	International Development Research Centre
IDS	Institute of Development Studies (UK)
IEA	International Energy Agency
IEG	Independent Evaluation Group (World Bank)
IFAD	International Fund for Agricultural Development
IFAS	International Fund for Saving the Aral Sea
IFI	international financing institution

IFPRI	International Food Policy Research Institute
IFRC	International Federation of Red Cross and Red Crescent Societies
IGAD	Inter-Governmental Authority on Development
IGRAC	International Groundwater Resources Assessment Centre
IGWA	Interagency Group on Water
IHA	International Hydropower Association
IIA	international investment agreement
IIED	International Institute for Environment and Development
IIRR	International Institute of Rural Reconstruction
IISD	International Institute for Sustainable Development
ILC	International Land Coalition
ILEC	International Lake Environment Committee
ILWRM	integrated land and water resources management
IMR	UN-Water Task Force on Indicators, Monitoring and Reporting
IPCC	Intergovernmental Panel on Climate Change
IRB	Indus River basin
IRI	International Research Institute for Climate and Society
IRS	indoor residual spraying
IRTCES	International Research and Training Center on Erosion and Sedimentation
IRWS	International Recommendations for Water Statistics
ISARM	Internationally Shared Aquifer Resources Management
ISET	Institute for Social and Environmental Transition
ISNAR	International Service for National Agricultural Research
ISO	International Organization for Standardization
ISPRA	Italian National Institute for Environmental Protection and Research
ISRIC	World Soil Information
ISWM	integrated stormwater management
ITCZ	Intertropical Convergence Zone
IUCN	International Union for Conservation of Nature
IUWM	integrated urban water management
IWA	International Water Association
IWLP	International Water Law Project
IWM	integrated water management
IWMI	International Water Management Institute
IWRM	integrated water resources management
IWROM	integrated water resources optimization model
JISAO	Joint Institute for the Study of the Atmosphere and Ocean
JMP	Joint Monitoring Programme for Water Supply and Sanitation (WHO/UNICEF)
JRV	The Jordan Rift Valley
KDP	World Bank-supported Kecamatan Development Project
LAC	Latin America and the Caribbean
LAS	League of Arab States
LBP	Lower Bhavani Project
LCB	Lerma Chapala River basin
LCBC	Lake Chad Basin Commission
LCRBC	Lerma Chapala River Basin Council
LDC	least developed country
LHWP	Lesotho Highlands Water Project
LLDC	land-locked developing country
LLIN	long lasting insecticide-treated mosquito net
LME	large marine ecosystem
LNMC	Libyan National Meteorological Centre
LPI	Living Planet Index
LVBWO	Lake Victoria Basin Water Office
LVWATSANI	Lake Victoria Region Water and Sanitation Initiative
MA	Millennium Ecosystem Assessment
MAP	Mediterranean Action Plan (UNEP)
MAR	managed aquifer recharge
MAWF	Ministry of Agriculture, Water and Forestry
MCED	Ministerial Conference on Environment and Development of the Asia-Pacific
MDB	Murray–Darling basin
MDBA	Murray–Darling Basin Authority
MDG	Millennium Development Goal
MDWPP	Multi-donor Water Partnership Programme
MEA	Millennium Ecosystem Assessment
MEA	multilateral environmental agreement
MEDAWARE	European Commission Euro-Mediterranean Partnership
MIGA	Multilateral Investment Guarantee Agency (World Bank)
MINAET	Ministry of Environment, Energy and Telecommunications (Mexico)
MPM	Marseille Provence Métropole Urban Community
MRB	Mara River basin
MRC	Mekong River Commission for Sustainable Development
MRI	Mortality Risk Index
MTWM	Ministry of Transport and Water Management (Netherlands)
MWI	Ministry of Water and Irrigation (Kenya)
MWP	Mondi Wetlands Programme (South Africa)
MWRWH	Ministry of Water Resources, Works and Housing (Ghana)
NADMO	National Disaster Management Organization (Ghana)
NAFTA	North American Free Trade Agreement
NAO	North Atlantic Oscillation
NAPA	National Adaptation Plan (or Programme) of Action
NAS	National Academy of Sciences
NCAR	National Centre for Atmospheric Research (USA)
NCASI	National Council for Air and Stream Improvement (USA)
NCMH	National Commission on Macroeconomics and Health (India)
NDMA	National Disaster Management Authority (China)
NDMP	National Disaster Management Plan (Ghana)
NEPAD	New Partnership for Africa's Development
NETL	National Energy Technology Laboratory
NFUS	National Farmers Union (Scotland)
NGO	non-governmental organization
NMHS	national meteorological and hydrological service
NOAA	National Oceanic and Atmospheric Administration (USA)
NRC	National Research Council (USA)
NRW	non-revenue water

NWC	National Water Commission (Australia)
NWC	National Water Council (Portugal)
NWI	National Water Initiative (Australia)
NWL	national water law
NWM	Indian National Water Mission
NWP	Nairobi Work Programme
NWP	National Water Policy (Mexico)
NWS	National Water Strategy (Jordan)
NWSC	National Water and Sewerage Corporation (Uganda)
OAU	Organisation of African Unity (now the African Union)
OBA	output-based aid
ODA	official development assistance (or aid)
OECD	Organisation for Economic Co-operation and Development
OKACOM	Okavango River Basin Trans-boundary Management Commission
OLADE	Latin American Energy Organization
OMVS	Organization for the Development of the Senegal River
ONE	Office National de l'Electricité (Morocco)
ONEP	Office National de l'Eau Potable (Morocco)
OSCE	Organization for Security in Central Europe
OSU	Oregon State University
OTA	Optimal Territorial Area (Italy)
PAHO	Pan American Health Organization
PCaC	Programa Campesino a Campesino (Nicaragua)
PCB	polychlorinated biphenyl
PDO	Pacific Decadal Oscillation
PEDDR	Partnership for Environment and Disaster Risk Reduction
PER	public expenditure review
PES	payment for ecosystem services
PGDAC	Piano di Gestione del Distretto dell'Appennino Centrale (Italy)
PID	Provincial Irrigation Department (China)
PIDA	Provincial Irrigation and Drainage Authority (China)
PMEL	Pacific Marine Environmental Laboratory (NOAA, USA)
PNA	Pacific North American Pattern
PNRC	Le Plan National de lutte contre le Réchauffement Climatique (Morocco)
POP	persistent organic pollutant
PoU	point-of-use
PPCPs	pharmaceuticals and personal care products
PPCR	Pilot Program for Climate Resilience
PPI	Private Participation in Infrastructure database (World Bank)
PPP	public-private partnership
PPWSA	Phnom Penh Water Supply Authority
PRB	Population Reference Bureau
PRESA	Pro-poor Rewards for Environmental Services in Africa
PRTA	Regional Plan for Water Protection (Italy)
PSI	Pilot Study on Indicators (WWAP)
PUB	prediction of ungauged basins
PURC	Public Utilities Regulatory Commission (Ghana)
PV	solar photovoltaic
PWTOA	Private Water Tanker Owners Association (Ghana)
R&D	research and development
RAED	Arab Network for Environment and Development
RBB	river basin board
RBC	river basin council
RBDA	river basin development authority (Nigeria)
RBDC	river basin district council
RBF	results-based financing
REDD	Reducing Emissions from Deforestation and Forest Degradation initiative (UNFCCC)
RMC	regional member country
RRC	River Restoration Centre (UK)
RWSSI	Rural Water Supply and Sanitation Initiative (AfDB)
SAARC	Comprehensive Framework on Disaster Management (India)
SABEP	Companhia de Saneamento Básico do Estado de São Paulo
SACI	South African Capacity Initiative
SADC	Southern African Development Community
SADC-DMC	SADC Drought Monitoring Centre
SAFE	surgery, antibiotics, facial cleanliness and environmental improvement
SALDRU	Southern Africa Labour and Development Research Unit
SAP	strategic action plan
SAPP	South African Power Pool
SARPN	South African Regional Poverty Network
SAWAF	South Asia Water Forum
SAWUN	Water Utility Network (South Asia)
SBSTA	Subsidiary Body for Scientific and Technological Advice (UNFCCC)
SDWA	Safe Drinking Water Act (USA)
SEE	South-Eastern Europe
SEEAW	UN System of Environmental-Economic Accounting for Water
SEI	Stockholm Environmental Institute
SEM	Société des Eaux de Marseille
SENARA	Servicio Nacional de Aguas Subterráneas, Riego y Avenamiento (Mexico)
SEPA	Scottish Environment Protection Agency
SES	socio-ecological system
SEWA	Self Employed Women's Association (Gujarat, India)
SIDS	small island developing states
SISS	Superintendencia de Servicios Sanitarios (Chile)
SIWI	Stockholm International Water Institute
SIWW	Singapore International Water Week
SJRB	St Johns River basin
SJR-WMD	St Johns River Water Management District
SLM	sustainable land management
SME	small and medium enterprises
SOC	soil organic carbon
SOM	soil organic matter
SOPAC	Pacific Islands Applied Geoscience Commission
SPI	Standardized Precipitation Index
SST	sea surface temperature
SSWM	sustainable sanitation and water management
SWA	Sanitation and Water for All global initiative
SWAP	sector-wide approach to planning
SWAR	surface water runoff
SWE	sectoral water efficiency
SWOT	strengths-weaknesses-opportunities-threats

TAC	Technical Advisory Committee of the Global Water Partnership
TAO	Tropical Atmosphere Ocean project
TARWR	total annual renewable water resources
TDS	total dissolved solids
TEEB	The Economics of Ecosystems and Biodiversity
TEST	transfer of environmentally sound technology
TMDL	total maximum daily load
TNC	The Nature Conservancy
TRB	Tiber River basin
TRB	Tagus River Basin
TRBA	Tiber River Basin Authority
TSG	Techknowledgy Strategic Group (USA)
TWB-MRB	Transboundary Water for Biodiversity and Human Health in the Mara River basin
UFW	unaccounted for water
UN ECOSOC	United Nations Economic and Social Council
UN	United Nations
UN-HABITAT	United Nations Human Settlements Programme
UNAG	National Union of Farmers and Ranchers (Nicaragua)
UNCCD	United Nations Convention to Combat Desertification
UNCSD	United Nations Conference on Sustainable Development
UNCTAD	United Nations Conference on Trade and Development
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNDRO	United Nations Disaster Relief Organization
UNECA	United Nations Economic Commission for Africa
UNECE	United Nations Economic Commission for Europe
UNECLAC	United Nations Economic Commission for Latin America and the Caribbean
UNEP	United Nations Environment Programme
UNEP/GEMS	Global Environment Monitoring System (UNEP)
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO-IHE	Institute for Water Education
UNESCO-IHP	International Hydrological Programme
UNESCWA	United Nations Economic and Social Commission for Western Asia
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
UNIDO	United Nations Industrial Development Organization
UNISDR	United Nations International Strategy for Disaster Reduction Secretariat
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNSD	United Nations Statistics Division
UNSGAB	United Nations Secretary General's Advisory Board on Water and Sanitation
UNU	United Nations University
UNU-WIDER	United Nations University World Institute for Development Economics Research

UNWAIS+	UN-Water Activity Information System
UNW-DPAC	UN-Water Decade Programme on Advocacy and Communication
UNW-DPC	UN-Water Decade Programme on Capacity Development
UPA	urban and peri-urban agriculture
USACE	United States Army Corps of Engineers
USAID	United States Agency for International Development
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USDOE	United States Department of Energy
USEPA	National Service Center for Environmental Publications (USA)
USEPA	United States Environmental Protection Agency
VBD	vector-borne diseases
WACF	Water Accounting Conceptual Framework
WAJ	Water Authority of Jordan
WAPDA	Water and Power Development Authority (China)
WAPP	West African Power Pool
WASH	water, sanitation and hygiene
WaterSHED	Water, Sanitation, and Hygiene Enterprise Development
WBCSD	World Business Council on Sustainable Development
WCD	World Commission on Dams
WDM	water demand management
WEC	World Energy Council
WEF	Water Environment Federation
WEF	World Economic Forum
WESSA	Wildlife and Environment Society of South Africa
WFD	Water Framework Directive (EU)
WFP	United Nations World Food Programme
WFP	Water Financing Program (ADB)
WFPF	Water Financing Partnership Facility
WHA	World Health Assembly
WHO	World Health Organization
WHYCOS	World Hydrological Cycle Observing System (WMO)
WIN	Water Integrity Network
WMO	World Meteorological Organization
WRC	Water Resources Commission (Ghana)
WRI	World Resources Institute
WRMA	Water Resources Management Authority (Kenya)
WSS	water supply and sanitation
WSSCC	Water Supply and Sanitation Collaborative Council
WSSD	World Summit on Sustainable Development
WTP	willingness to pay
WUA	water users association
WWAP	World Water Assessment Programme
WWC	World Water Council
WWDR	World Water Development Report
WWF	World Water Forum
WWF	World Wide Fund for Nature
WWTP	wastewater treatment plant
YRB	Yellow River basin
YRCC	Yellow River Conservancy Commission

'Anthropocene' A new geological epoch so named because humans have come to rival nature in their impact on the physics, chemistry and biology of the global environment.

ablation The removal of material from the surface of an object by vaporization, chipping or other erosive processes. Ablation constitutes a key part of glacier mass balance. The ablation zone refers to the low altitude area of a glacier or an ice sheet where there is a net loss in ice mass due to melting, sublimation, evaporation or calving.

abstraction The process of taking water from a source, either temporarily or permanently.

acid rain The precipitation of dilute solutions of strong mineral acids, formed by the mixing in the atmosphere of various industrial pollutants, primarily sulphur dioxide and nitrogen oxides, with naturally occurring oxygen and water vapour.

adaptation Any alteration in the structure, function or behaviour of an organism, an institution or a society as its external environment changes so that it becomes better able to survive, multiply and achieve its goals, as applicable, in its changing environment.

adaptation tipping point The costs, risks and impacts of climate change will increase over time to the point when they challenge the expectations of resource managers and the business community as they make decisions.

adaptive capacity The capacity of a system (e.g. ecological or human social) to adapt if the environment where the system exists is changing.

adaptive decision-making Approaches and techniques for addressing problems over time in response to changing conditions.

adaptive management A type of natural resource management where adjustments are made in response to project monitoring, new information, and changing social conditions that may indicate the need to change a course of action. The aim is to learn about the system and improve system performance over time.

adaptive planning Planning methods that consider adaption to changing and uncertain conditions over time to achieve improved performance, more effective or efficient resource use, increased benefits, reduced costs and so forth.

adaptive strategy Planning or management strategy that can change depending on changing environmental conditions or changing objectives.

adaptive water management Water management policies that can adapt to changing conditions and objectives over time.

advance market commitment A binding contract, typically offered by a government or other financial entity, used to guarantee a viable market if a product is successfully developed.

Aflaj A system of tapping underground water which is led by man-made subterranean channels to villages where it is used for irrigation and domestic purposes.

agriculture Activities related to the growing and production of animals and crops that can take place either given the natural rainfall patterns (rainfed agriculture) or with the application of additional water (irrigation), often from surface or groundwater sources.

agriculture-to-urban water transfer When water supplies that traditionally have been allocated to agriculture activities are allocated to urban areas to help meet their demands.

aquaculture Also known as aquafarming, the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants. Commercial fishing is the harvesting of wild fish.

AQUASTAT The global information system on water and agriculture developed by the Land and Water Division of the Food and Agriculture Organization of the United Nations (FAO).

aquifer A water body occupying pore space in the Earth or rock formations under the surface of the Earth. Fossil aquifers take thousands of years to build – and rebuild (or recharge).

arable cropping The process of growing crops on land that can be ploughed.

Arctic Oscillation (AO) Also known as Northern Annular Mode/Northern Hemisphere Annular Mode (NAM), an index of the dominant pattern of non-seasonal sea-level pressure variations north of 20° latitude, characterized by pressure anomalies of one sign in the Arctic with the opposite anomalies centred 37–45°N.

arid region Characterized by a severe lack of available water, to the extent of hindering or even preventing the growth and development of plant and animal life. There is no universal agreement on the precise boundaries between classes such as 'hyper-arid' or 'semi-arid'.

Aridity Index (AI) A numerical indicator of the degree of dryness of the climate at a given location. A number of AIs have been proposed; these indicators serve to identify, locate or delimit regions that suffer from a deficit of available water, a condition that can severely affect the effective use of the land for such activities as agriculture or stock-farming.

Atlantic Meridional Overturning Circulation (AMOC) Carries warm upper waters into far-northern latitudes and returns cold deep waters southward across the Equator. Its heat transport makes a substantial contribution to the moderate climate of maritime and continental Europe.

Atlantic Multidecadal Oscillation (AMO) Variability of the sea surface temperature in the North Atlantic Ocean.

Backcasting Reverse-forecasting technique which starts with a specific future outcome and then works backwards to identify policies and programmes that will connect to the present conditions. Forecasting is the process of predicting the future based on current trend analysis.

ballast water Fresh or salt water, sometimes containing sediments, held in tanks and cargo holds of ships to increase stability and manoeuvrability during transit. The discharge of water from ballast tanks has been responsible for the introduction of species that cause environmental and economic damage.

basin closure When supply of water falls short of commitments to fulfil demand in terms of water quality and quantity within the basin and at the river mouth, for part or all of the year, basins are said to be closing or closed. Basin closure can be an anthropogenic process.

Bayesian network A graphical model that encodes probabilistic relationships among variables of interest. It can be used to learn causal relationships, and hence predict the consequences of intervention.

behavioural decision theory Theory on how people make judgments and choices, and how the processes of decision might be improved using concepts and tools from psychology, economics, statistics and other disciplines. People's behaviour is based on their perception of what reality is, not on reality itself.

benefit transfer approach Method used to estimate economic values for ecosystem services by transferring available information from studies already completed in another location or context.

biochemical oxygen demand (BOD) The amount of oxygen needed by microorganisms digest the organic material in a unit volume of water at a given temperature and for a given time. It is an index of the degree of organic pollution in water.

biodiversity The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. The totality of genes, species and ecosystems in a region.

biofuel Organic material – produced by plants, animals or microorganisms – such as sugar cane stalks, leaves or animal dung, that can be burned directly as a heat source or converted into a gaseous or liquid fuel. These fuels can be used for any purposes, but the main use is in the transportation sector.

biomass energy The energy derived from the carbon, hydrogen and oxygen in biomass. Biomass energy is derived from five distinct energy sources: garbage, wood, waste, landfill gases and alcohol fuels.

biome The complex of living communities (including humans) maintained by the climate of a region and characterized by a distinctive type of vegetation, such as tundra, tropical forest, steppe and desert.

black water Wastewater containing faeces.

blue water Natural surface water and groundwater.

bottom billion The almost one billion people who live in the 60 or so impoverished countries that have failed to progress despite international aid and support. Coined by Paul Collier in the 2007 book *Why the Poorest Countries are Failing and What Can Be Done About It.*

bottom-up approach A stakeholder-driven approach to planning and decision-making as opposed to a government top-down approach that dictates to the stakeholders what decisions will be made.

BRIC(S) countries Brazil, Russian Federation, India, China (and South Africa). The WWDR4 uses both terms (BRIC and BRICS) as BRICS is a new development and not all statistics and descriptors have been updated to include South Africa in the group.

brittleness (as a characteristic of a solution) The likelihood of failure should input variable values deviate from those expected and for which the solution was designed.

business-as-usual approach Proceeding as in the past, in the usual prescribed manner without changing any policy or plan.

capacity The ability to perform and accomplish particular tasks. Capacity-building and capacity development usually refers to educational programmes designed to give individuals the knowledge and skills needed to perform given tasks.

carbon credit A generic term for any tradable certificate or permit representing the right to emit one tonne of carbon dioxide or the mass of another greenhouse gas (GHG) with a carbon dioxide equivalent to one tonne of carbon dioxide. Carbon credits and carbon markets are a component of national and international attempts to mitigate the growth in concentrations of GHGs. Carbon trading is an application of an emissions trading approach.

carbon cycle The biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere and atmosphere of the Earth. It allows for carbon to be recycled and reused throughout the biosphere and all of its organisms.

carbon sequestration Capturing and storing carbon discharges to the atmosphere in carbon sinks (such as oceans, forests or soils) to either mitigate or defer global warming and avoid dangerous climate change.

cash crop Crop grown for sale as opposed to for consumption by those who grew them on the farm (subsistence crop).

catastrophe modelling Development and use of models that predict risks of catastrophic events.

clean energy Sources of energy that do not pollute the environment or discharge greenhouse gases into the atmosphere, such as energy derived from the sun, tides and wind. Hydropower and nuclear energy sources are also often considered clean.

clientelism Term used to describe a political system at the heart of which is an asymmetric relationship between groups of political actors described as patrons and clients.

climate change Climate change refers to any significant change in measures of climate (such as temperature, precipitation or wind) lasting for an extended period (decades or longer). Climate change can result from natural processes or human activities. Mitigation refers to measures that reduce any adverse impacts from climate change. Adaptation refers to measures that are taken to better manage systems as they change due to a changing climate. Forcing is a process that alters the energy balance of the climate system; that is, changes the relative balance between incoming solar radiation and outgoing infrared radiation from Earth.

Climate Vulnerability Index (CVI) A function dependent on climate exposure, resilience and adaptability. The CVI uses water as a focus as it is a key factor of human and ecological well-being.

climate-smart cropping Measures to conserve nutrients, water and biodiversity in ways that increase crop yields.

closed-loop production system An environmentally friendly production system in which any industrial residual output is capable of being recycled to create another product.

command-and-control approach An approach in which a regulatory body or political authority dictates a behaviour or how some goal is to be achieved. In environmental policy, this basically involves the setting of standards to protect or improve environmental quality.

conditional cash transfer (CCT) Programmes that aim to reduce poverty by making welfare programs conditional upon the receivers' actions. The government transfers the money only to persons who meet certain criteria.

conservation agriculture Practices that aim to achieve sustainable and profitable agriculture and subsequently improved livelihoods of farmers through minimal soil disturbance, permanent soil cover and crop rotations.

convertible loan Loan that entitles the lender (or the holder of loan debenture) to convert the loan to common or preferred stock (ordinary or preference shares) at a specified conversion rate and within a specified timeframe.

corporate social responsibility (CSR) A form of corporate self-regulation integrated into a business model. The goal is to embrace responsibility for the company's actions and encourage a positive impact through its activities on the environment, consumers, employees, communities, stakeholders and the public.

corruption Inducement to wrong by improper or unlawful means such as bribery.

cost–benefit–risk analysis Procedure for calculating and evaluating the benefits, costs and risks of a proposed project.

cradle-to-cradle Industrial design and operation paradigm based on the principles and an understanding of the pursuit of value, processes for product and material research and development, and for educating and training. Cradle-to-cradle principles encourage making waste into food and fuel just as nature does; they seek to create systems that are not just efficient but essentially waste free.

crop per drop The amount or value of product over volume or value of water depleted or diverted to produce it.

cross-cutting (issue) Topic of concern to several different sectors or interests that include subjects such as education, finance and budgeting, personnel management and security, trade, technology transfer, consumption and production patterns, science, capacity-building and information.

cryosphere Portions of the Earth's surface where water is in solid form, including sea ice, lake ice, river ice, snow cover, glaciers, ice caps and ice sheets, and frozen ground (which includes permafrost).

decision rules (minimax, maximin) Strategies or policies that minimize the worst that can happen (i.e. minimize the maximum adverse aspect or impact or measure of system performance) or that maximize the least beneficial aspect, impact or measure of system performance.

decision-scaling Identifying what kind of climate changes would cause problems and then turning to the climate models to estimate whether those climate changes are likely.

decision-support tool Tools such as models that inform the process of decision-making. Often these are interactive menu-driven computer-based programmes.

deforestation The removal of forests and forest cover, often for the purpose of agriculture, urban or industrial development.

delta A landform that is formed at the mouth of a river where that river flows into an ocean, sea, estuary, lake, reservoir, flat arid area or another river, from the deposition of the sediment carried by the river as the flow leaves the mouth.

demand hardening As a water user becomes more efficient in the use of water, it becomes more difficult to save increased amounts of water during a shortage or drought.

demand management measure An action that is meant to ensure greater availability of resources to meet the level of requests.

demography The study of the characteristics of human populations, such as size, growth, density, distribution and vital statistics.

desalination Removal of salt and other impurities from sea or brackish surface or groundwater.

desertification Land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities.

disaster risk management (DRM) Measures taken to reduce the risks of human suffering and economic losses caused by natural and technological disasters.

disaster risk reduction (DRR) The practice of reducing disaster risks through systematic efforts to analyse and reduce the causal factors of disasters.

discounting Determining the value of some amount of money in an earlier time period taking into account the time value of money. It is the opposite of compounding, and requires the use of an interest rate applicable to the time interval being considered.

dissolved oxygen (DO) The amount or concentration of oxygen in a medium, such as water. The DO deficit from its saturation concentration is a common indicator of the degree of organic pollution in a water body.

diversification The variability or richness of types of species or organisms in ecosystems or types of investments in investment portfolios that decrease the risks of major failures in ecosystems or of large economic losses, as applicable.

driver Force or event outside the system of interest that affect its behaviour or performance directly or indirectly.

drought The naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.

drought-resilient crop Crop that is able to survive and recover from extended dry periods. Drought-resistant crops typically refer to crops that have been subjected to plant breeding to improve their ability to survive in periods of extended water shortage.

drylands Arid, semi-arid and dry sub-humid areas, other than polar and subpolar regions, in which the ratio of annual precipitation to potential evapotranspiration falls within the range from 0.05 to 0.65.

dry-year option Contractual agreements that provide for voluntary and temporary drought-triggered water transfers.

durable consumption rate Rate of consumption of goods that do not quickly wear out, or more specifically, goods that yield utility over time rather than being completely consumed in one use.

early warning system Technology designed to provide advanced warning of pending hazards or other events.

eco-efficiency water infrastructure guidelines Procedures for designing water infrastructure for the delivery of competitively priced goods and services that satisfy human needs and improve quality of life, while progressively reducing ecological impacts and resource use.

eco-innovation The commercial application of knowledge to elicit direct or indirect ecological improvements.

ecological footprint The biologically productive land and water area that a person or population requires from around the world to produce the resources consumed and to absorb the wastes generated using prevailing technology.

ecosystem A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.

ecosystem/environmental infrastructure Infrastructure that provides ecosystem services such as water purification, flood control, recreation and climate stabilization.

ecosystem services (and goods and functions) Any aspect of ecosystem structure and function that has an economic, social or cultural value, known or unknown, to its inhabitants.

ecosystem tipping point A threshold at which a relatively small change causes a rapid change in an ecosystem. When the threshold has been passed, the ecosystem may no longer be able to return to its previous state.

effluent The discharge from a wastewater treatment plant, or water user.

El Niño-Southern Oscillation (ENSO) A quasiperiodic complex climate pattern that occurs across the tropical Pacific Ocean roughly every five years, with impacts such as floods and droughts.

energy Primary energy is an energy source found in nature that has not been subjected to any conversion or transformation process. It can be renewable or non-renewable. Secondary energy is derived from primary energy sources; for example, electricity, transformed from such primary sources as coal, oil, natural gas and wind.

energy–climate–water cycle This cycling of water is intimately linked with energy exchanges among the atmosphere, ocean, and land that determine the Earth's climate and cause much of natural climate variability.

environmental flow The core objective of river basin management. Instream or river flows and regime designed to maintain healthy aquatic ecosystems in the stream or river. Waters allocated to environmental flows are not available for withdrawals to off-stream users.

environmental management accounting (EMA) A business tool for creating internal demand in businesses for cleaner and less wasteful production processes.

environmental management system (EMS) Management of an organization's environmental programmes in a comprehensive, systematic, planned and documented manner. An EMS offers a structured way to incorporate environmental considerations into day-to-day operations.

environmental/ecosystem assessment Estimation of the adverse effects that human activities and pollutants have on an ecosystem.

estuary A bay or inlet often at the mouth of a river in which large quantities of freshwater and saltwater mix together.

eutrophication The nutrient enrichment of waters that stimulates an array of symptomatic changes, among which increased production of algae and macrophytes, deterioration of water quality and other changes are considered undesirable and interfere with water users.

evapotranspiration Water released to the atmosphere through evaporation from the ground and water surfaces and from the leaf surface of plants (transpiration).

extraction The process of locating, acquiring, removing and selling any resource.

extreme (hydrological) event Unusual hydrological conditions rarely observed, such as floods, droughts, temperatures, winds and storms.

fit-for-purpose structure A structure that is suitable and good enough to do the job it was designed to do. 'Fit-for-purpose' is one of the principles for quality assurance.

flash flood Flash floods are short-term events, occurring within six hours of the causative event (heavy rain, dam break, levee failure, rapid snowmelt or ice jam) and often within two hours of the start of high intensity rainfall.

floodplain Mostly flat land adjacent to a river, formed by the actions of the river. Floodplains are beneficial for reducing the number and severity of floods.

food security Having, at all times, both physical and economic access to sufficient food to meet dietary needs for a productive and healthy life. Food security is built on food availability, access and use.

food wastage Food wastes are the organic residues generated by the handling, storage, sale, preparation, cooking and serving of food. Food wastage is a symptom of developed countries' consumerism.

fossil fuel, hydrocarbon A broad name given to a variety of fuels found in the Earth. These fuels have the name fossil fuels because they probably formed from the remains of ancient decaying organisms.

free-riding In economics, collective bargaining, psychology and political science, free-riding refers to the behaviour of consuming a resource without paying for it, or paying less than the full cost. It is usually considered to be an economic problem only when it leads to the non-production or under-production of a public good or when it leads to the excessive use of a common property resource.

freshwater Water containing less than 1,000 milligrams per litre of dissolved solids, most often salt. It naturally occurs on the Earth's surface in ice sheets, ice caps, glaciers, bogs, ponds, lakes, rivers and streams, and underground as groundwater in aquifers and underground streams. This term specifically excludes seawater and brackish water although it does include mineral rich waters such as chalybeate springs.

glacier A large persistent body of ice that forms where the accumulation of snow exceeds its ablation (melting and sublimation) over many years, often centuries. Glacial ice is the largest reservoir of freshwater on Earth.

glacier lake outburst flood (GLOF) and outbursts of glacier-dammed lakes (jökulhlaups) As glaciers retreat due to increasing temperatures, glacial lakes start to form and rapidly fill up behind natural moraine or ice dams at the bottom or on top of these glaciers. The ice or sediment bodies that contain the lakes can breach suddenly, leading to a discharge of volumes of water and debris.

global trade in water resources Long-distance transfers of water in direct or indirect (virtual) form, where virtual water is the volume of water that has been used to produce a commodity and that is thus virtually embedded in it.

global warming The rising average temperature of Earth's atmosphere and oceans and its projected continuation.

globalization The increasingly global relationships of culture, people and economic activity.

governance Decisions that grant power, or verify performance. Governance is either a part of management or leadership processes or a separate process. These processes and systems are typically administered by a government. Water governance is the set of formal and informal processes through which decisions related to water management are made.

green economy An economy that results in improved human well-being and social equity while significantly reducing environmental risks and ecological scarcities. Its most distinguishing feature from prior economic regimes is direct valuation of natural capital and ecological services as having economic value.

green infrastructure The collection of 'life support' functions provided by a network of natural ecosystems, with an emphasis on interconnectivity to support long-term sustainability. Examples include clean water and healthy soils, flood protection, as well as the more anthropocentric functions such as recreation and providing shade and shelter in and around towns and cities.

green water The precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. Green water can be made productive for crop growth (but not all green water can be taken up by crops, because there will always be evaporation from the soil and because not all periods of the year or areas are suitable for crop growth).

greenhouse gas (GHG) A gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. The primary GHGs in the Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide, and ozone.

grey water Polluted water that results from non-sanitary uses of water (e.g. dishwashing, showers).

Gross Domestic Product (GDP) The market value of all final goods and services produced within a country in a given period. GDP per capita is often considered an indicator of a country's standard of living. It is not to be confused with Gross National Product (GNP), which allocates production based on ownership.

groundwater Aquifer storage changes depending on the water withdrawn (abstracted) and added (recharge) over time. Aquifer storage can act as a buffer, permitting withdrawals during periods of low recharge, as long as the deficit is reduced during periods of relatively high recharge.

hard infrastructure, hard engineering approach Large physical networks necessary for the functioning of a modern industrial nation.

health impact assessment (HIA) A means of assessing the health impacts of policies, plans and projects in diverse economic sectors using quantitative, qualitative and participatory techniques.

household water security The reliable availability of safe water in the home for all domestic purposes. The term has both a quantity and a quality component.

Human Development Index (HDI) A tool developed by the United Nations to measure, track and compare countries' levels of social and economic development based on four criteria: life expectancy at birth, mean years of schooling, expected years of schooling, and gross national income per capita.

human well-being A state of health, happiness and prosperity; of being with others, where human needs are met, where one can act meaningfully to pursue one's goals, and where one enjoys a satisfactory quality of life.

hydroelectricity Electricity generated from a hydropower plant that typically uses water from a storage reservoir to drive turbines that generate the electricity.

hydro-geological dataset Databases containing values of hydrological and geological parameters and variables.

hydrographic network The sum total of water bodies and streams on land (rivers, lakes, swamps and water reservoirs).

hydrological cycle = hydrologic cycle = H_2O cycle = water cycle The circulatory flux of water at or near the Earth's surface.

hydrological record Recorded time series data of hydrological variable values such as streamflows, precipitation, groundwater levels and water quality constituent concentrations, obtained from monitoring.

hydrometeorology A branch of meteorology and hydrology that studies the transfer of water and energy between the land surface and the lower atmosphere.

hydromorphological alteration/modification Human pressure on the natural structure of surface waters such as modification of bank structures, sediment/habitat composition, discharge regime, gradient and slope.

impacts thinking Thinking that has been impacted by external events.

indeterminacy The quality of something being uncertain, or incalculable.

indicator A measure that indicates the state of something else. In ecology, an organism or ecological community so strictly associated with particular environmental conditions that its presence is indicative of the existence of these conditions. In economics, any of a group of statistical values that taken together give an indication of the health of the economy.

institution Interpersonal networks of groups of individuals (informal institutions) that deal with social issues evolve as society develops economically into formal institutions of a market-based economy, such as a structured system of laws imposed by representative forms of governance.

integrated pest management Effective and environmentally sensitive approach to pest management that relies on comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means, and with the least possible hazard to people, property and the environment.

integrated plant nutrition management Use of nutrients in a yield-targeted, site-and soil specific way; understanding the inter-relation of different nutrients; use of combinations of mineral and organic fertilizers; provision of nutrients on a cropping-system/rotation basis; and use of on-farm and off-farm waste through recycling.

integrated urban water management (IUWM) The practice of managing freshwater, wastewater and stormwater as links within the resource management structure, using an urban area as the unit of management.

integrated water resources management (IWRM) A systematic process for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives.

irrigation The science of artificial application of water to the land or soil. In surface irrigation systems, water moves over the land by simple gravity flow in order infiltrate into the soil. In drip irrigation, the water is placed drop by drop near the root zone of the plants. Ground and rainfed sources obtain their water from groundwater and rainfall respectively.

jet stream Relatively strong winds concentrated within a narrow stream in the atmosphere.

knowledge management The branch of management that seeks to improve performance in business by enhancing an organization's capacity to learn, innovate and solve problems.

land and water rights The relationship, whether legally or customarily defined between people, as individuals or groups, with respect to land. In essence a water right is a legal right: to abstract or divert and use a specified quantity of water from a natural source; to impound or store a specified quantity of water in a natural source behind a dam or other hydraulic structure; or to use water in a natural source.

land degradation Reduction or loss of the biological or economic productivity and complexity of land, resulting from processes, including processes arising from human activities and habitation patterns, such as (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation.

land management Process by which the resources of land are put to good effect, from an environmental and an economic perspective.

land subsidence Sinking elevation of the ground surface, which may occur over an aquifer that is slowly draining and decreasing in volume because of pore collapse.

large-scale land acquisition Gaining of tenure rights to large areas of land through purchase, lease, concession or other means.

least developed countries (LDCs) A group of countries that have been identified by the United Nations as 'least developed' in terms of their low gross national income, their weak human assets and their high degree of economic vulnerability.

livelihood A means of support or subsistence.

low-flow appliance An appliance that is designed to reduce water consumption without compromising performance of the appliance.

managed aquifer recharge (MAR) The process of adding a water source such as recycled water to aquifers under controlled conditions for withdrawal at a later date, or of using the water source as a barrier to prevent saltwater or other contaminants from entering the aquifer.

megacity A city that has a population of more than 10 million people and that is often made of two or more urban areas that have grown so much they have become connected.

microfinance The goal of microfinance is to give low-income people an opportunity to become self-sufficient by providing a means of saving money, borrowing small amounts of money through microcredit, and buying micro-insurance for lower valued assets.

Millennium Development Goal (MDG) Goals that aim to improve human well-being by reducing poverty, hunger, child and maternal mortality, ensuring education for all, controlling and managing diseases, tackling gender disparity, ensuring sustainable development, and pursuing global partnerships.

Millennium Ecosystem Assessment Identification of the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance conservation and sustainable use of those systems.

modular water treatment design Design of pre-fabricated, self-contained and transportable water treatment facilities.

monsoon The seasonal wind of the Indian Ocean and southern Asia, blowing from the southwest in summer and northeast in the winter.

moraine An accumulation of earth and stones carried and finally deposited by a glacier.

multilateral environmental agreement An agreement created by the United Nations between multiple nations that pledge to conduct trade operations in such a way that limits negative environmental impacts.

nexus A connected group or series of interdependent components.

nitrate vulnerable zone Areas of land that drain into nitrate polluted water, or water that could become polluted by nitrates.

non-consumptive production process Production processes that may use but do not consume water. Examples include the water used for hydropower electricity production and that used for cooling of thermoelectric power plants.

nonstationarity, nonstationary probabilities Changing probability distributions or their parameters over time.

no-regrets decision A decision taken by households, communities or institutions that can be justified from economic, social and environmental perspectives regardless of future changes in external conditions.

North Atlantic Oscillation (NAO) The large-scale seesaw in atmospheric mass between the subtropical high and polar low.

official development assistance/aid (ODA) The amount that a nation expends through grants and other development assistance programs calculated as a percent of gross national product.

output-based aid (OBA) Development aid strategies that link the delivery of public services in developing countries to targeted performance-related subsidies.

Pacific Decadal Oscillation (PDO) A pattern of Pacific climate variability that shifts phases on at least an inter-decadal time scale, usually 20 to 30 years.

path dependence Explains how the set of decisions faced for any given circumstance is limited by the decisions made in the past, even though past circumstances may no longer be relevant.

payment for ecosystem/environmental services (PES) The practice of offering incentives to farmers or landowners in exchange for managing their land to provide some sort of ecological service.

peak ecological water The point beyond which the total costs of ecological disruptions and damages exceed the total value provided by human use of that water.

peak renewable water A term applied where flow constraints limit total water availability over time.

percolation rate The rate at which water moves through saturated granular material.

peri-urban slum/area About a third of the world's slum dwellers live in traditional inner cities, but most live on the peripheral edge in peri-urban slums – sprawling, endless slum-suburbs.

photobioreactor (PBR) A device that houses and cultivates algae. It provides a suitable environment for algae growth, supplying light, nutrients, air and heat to the culture, in addition to protecting the culture from contamination.

phreatophytic agriculture A type of agriculture focusing on deep-rooted plants that obtain water from the water table or the layer of soil just above it.

physical flood defence system Levees, weirs, dykes and reservoirs – systems in place to protect areas from flood devastation.

point-of-use (PoU) water treatment/technology A method of water treatment used to improve water quality for an intended use at the point of consumption instead of at a centralized treatment facility.

polluter pays principle In environmental law, the polluter pays principle is enacted to ensure the party responsible for producing pollution is responsible for paying for the damage done to the natural environment.

pollution abatement technology Technology that is designed to reduce the concentration of contaminants in water or on land.

pollutant/pollution Contaminants in a natural environment that cause instability, disorder, harm or discomfort to the ecosystem or reduce the value of environmental media for other uses. Point source pollution is a single identifiable localized source of pollution. Non-point source pollution comes from many diffuse sources – by airborne deposition as well as from rainfall or snowmelt moving over and through the ground. Diffuse source pollution has no specific point of discharge.

portfolio theory Theory of investment which attempts to maximize portfolio expected return for a given amount of portfolio risk, or equivalently minimize risk for a given level of expected return, by carefully choosing the proportion of various assets.

potable/non-potable water Potable water is suitable for human consumption; non-potable water is not.

precautionary principle States that if an action or policy has a suspected risk of causing harm to the public or to the environment, in the absence of scientific consensus that the action or policy is harmful, burden of proof that it is not harmful falls on those taking the action.

protectionist policy, protectionism The economic policy of restraining trade between states through methods such as tariffs on imported goods, restrictive quotas and a variety of other government regulations designed to allow 'fair competition' between imports and goods and services produced domestically.

public–private partnership (PPP) A government service or private business venture which is funded and operated through a partnership of government and one or more private sector companies.

Ramsar convention An intergovernmental treaty that embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance and to plan for the 'wise use' or sustainable use of all of the wetlands in their territories.

recharge Groundwater recharge is a hydrological process where water moves to groundwater. Surface water recharge is a hydrological process where water runs off to surface watercourses.

reclaimed water Former wastewater (sewage) that is treated to remove solids and certain impurities, and is used in landscaping, irrigation, industrial cooling, or to recharge groundwater aquifers. The purpose of these processes is water conservation, rather than discharging the treated water to surface waters such as rivers and oceans.

reservoir rule/guide curve A reservoir release policy specifying releases as a function of existing storage level or volume and time of year, or specifying a target storage value given the time of year and sometimes the inflow as well.

resilience A measure of the ability of a system to recover from an unsatisfactory state.

results-based financing (RBF) Ties the disbursement of subsidies (or aid) to the delivery of actual results. For example, a carbon finance strategy involves mitigation policies and market mechanisms to create an environment that promotes diverse energy sources and incentives for new and cleaner technologies.

retention capacity The capacity to store and hold water, such as in soil.

rights-based approach Use of human rights as a framework to guide the development process.

risk Probability of an undesirable outcome.

risk management The identification, assessment and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor and control the probability or impact of unfortunate events or to maximize the realization of opportunities.

river gauging station Site and facility where the river flow or stage is being measured and recorded.

riverine flood protection Measures taken to protect areas on the floodplain from experiencing a flood, such as flood proofing, levees and upstream reservoir flood storage capacity.

robustness A measure of how well a system, strategy or decision may perform or function given a range of possible inputs, not all of which are predicted.

runoff Surface flow from land areas during and after a storm or precipitation event.

run-of-the-river dam A reservoir that is created by a dam and whose storage volume is maintained at a constant value, so that the inflow equals the outflow less any losses.

rural zoning Land use and development that is restricted to rural uses and activities.

saltwater intrusion The infiltration or flow of saltwater into fresh surface or groundwater bodies.

sanitation The provision of infrastructure, facilities and services for the safe disposal of human urine and faeces. Inadequate sanitation is a major cause of disease worldwide.

scenario An account or synopsis of a projected course of action, event or situation. Scenario development is used in policy planning, organizational development and generally, when organisations wish to test strategies against uncertain future developments.

sectoral water efficiency (SWE) Measure (ratio) of efficiency based on inputs and outputs.

sector-wide approach to planning (SWAP) An approach wherein planning and activity is at the whole of sector level, and the many aspects of a sector are taken into consideration (capacity of personnel, institutional strength, stakeholder consultation, implementation processes, monitoring, financing and so on).

sensitivity analysis The study of how the variation (uncertainty) in the output of a model can be attributed to different variations in the inputs of the model.

sewage administration Administration of wastewater collection and treatment systems typically so that they produce enough revenues to fund their own activities.

sewage, sewerage Domestic wastewater typically collected in sewers or ditches and treated in wastewater treatment plants or discharged as is into water bodies.

smallholder An individual farming on a small area of land, less than the size of a small farm.

snowpack Layers of snow that accumulate in geographic regions and high altitudes where the climate includes cold weather for extended periods during the year.

social learning Observational learning can occur in relation to an actual person demonstrating the desired behaviour – an individual describes the desired behaviour in detail, and instructs the participant in how to engage in the behaviour – through the media, including, movies, television, Internet, literature and radio.

socio-ecological system (SES) A bio-geo-physical unit and its associated social actors and institutions. Socio-ecological systems are complex and adaptive and delimited by spatial or functional boundaries surrounding particular ecosystems and their problem context.

soft infrastructure All the institutions that are required to maintain the economic, health, cultural and social standards of a country, such as the financial system, the education system, the health care system, the system of government, law enforcement, and emergency services.

soft path (approach, measure, infrastructure, policy) The soft path integrates both supply and demand concepts, recognizing that water is a means to satisfy demands for goods and services, and asks how much water, of what quality, is actually required to satisfy those demands efficiently and sustainably.

stakeholder A person, group, organization or system who affects or can be affected by an organization's actions.

stationary hydrology The probabilistic nature of hydrological processes is not changing over time.

stochastic analysis The analysis of random processes that take place over time.

storm surge An offshore rise of water typically associated with a low pressure weather system.

storm track Relatively narrow zones in the Atlantic and Pacific Oceans along which most Atlantic or Pacific extratropical cyclones or hurricanes travel.

supply-side infrastructure Infrastructure designed to provide the supply and quality of water or energy needed to meet the demand.

surface water Water located on the surface of the Earth, such as in streams, rivers, lakes, seas and oceans.

surprise (in a system) System behaviour or performance that is not expected or foreseen.

sustainability, sustainable development The capacity to endure. The long-term maintenance of environmental, economic and social aspects such that the quality of life is improved over time.

sustainable land management (SLM) Managing land for productivity in agriculture and forestry while providing environmental protection and ecosystem services and taking into account demographic growth and increasing pressure in land use.

sustainable water management The use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it.

TARWR (total actual renewable water resources) The theoretical maximum annual volume of water resources available on a sustainable basis in a country.

technocratic knowledge Any kind of management or administration by specialized experts selected through bureaucratic processes on the basis of specialized knowledge and performance, rather than democratic election.

teleconnections Links among world climate anomalies. Teleconnection pattern refers to a recurring and persistent large-scale pattern of pressure and circulation anomalies that span vast geographical areas.

tipping point The point at which a slow, reversible change becomes irreversible, often with dramatic consequences.

top-down approach An approach to decision-making where an executive, decision-maker or other person or body makes a decision. This approach is disseminated under their authority to lower levels in the hierarchy, who are, to a greater or lesser extent, bound by them.

transboundary basin, aquifer A river basin or groundwater aquifer that spans multiple political entities, separated by boundaries.

trialogue approach Links science, government and society.

unaccounted-for water (UfW) Water that has been produced and is 'lost' before it reaches the customer.

uncertainty Lack of sureness about something. Uncertainty may range from a falling short of certainty to an almost complete lack of conviction or knowledge, especially about an outcome or result.

urban and peri-urban agriculture (UPA) The practice of cultivating, processing and distributing food in, or around, a village, town or city. It can involve animal husbandry, aquaculture, agro-forestry and horticulture.

urbanization The physical growth of urban areas as a result of global change. Urbanization can represent the level of urban relative to overall population, or it can represent the rate at which the urban proportion is increasing.

value chain (agriculture, food) The full range of activities, with maximum generation of value, that are required to bring a product (or a service) from conception through the different phases of production to delivery to final consumers and disposal after use.

virtual (embedded) water The water used in the production of a good or service.

vulnerability Degree to which people, property, resources, systems and cultural, economic, environmental and social activity is susceptible to undesired outcomes, harm, degradation or destruction.

wadi The Arabic term traditionally referring to a valley.

wastewater Any water that has been adversely affected in quality by human influence.

water accounting Keeping track of the water resources in a river basin, indicating where water is going, how it is being used, and how much remains available for further use.

water allocation system Institutional structure for allocating water. The choice of structure is ultimately a compromise between the physical nature of the resource, human reactions to policies, and competing social objectives.

water balance (in industry) A description of the flow of water in and out of an industrial system.

water bank An institutional mechanism used to facilitate the legal transfer and market exchange of various types of surface water, groundwater and water storage entitlements.

'water box' The collection of activities and organizations that assess, develop and manage water resources. This is in contrast to those who make decisions in their respective economic sectors that have impacts on the decisions and options of those within the water box.

water conservation The reduction of the usage of water and recycling of waste water for different purposes such as cleaning, manufacturing and agricultural irrigation.

water conveyance The transport of water from one place to another, such as in a canal, pipeline or aqueduct.

water demand management Measures taken to alter the demand for water, as opposed to supply management measures that attempt to meet the demands.

water development agenda A comprehensive blueprint of action to be taken by organizations and major groups with respect to water development that can impact on human welfare.

water dialogue space A space that allows individuals within multistakeholder groups to resolve real but 'neutral' problems and thereby build trust and mutual respect.

water distribution The percentages of volumes of fresh and saline water, both on and under the surface of the Earth. Alternatively, the transport of water supplies from water treatment plants to particular water users in an urban area.

water diversion The withdrawal and transport of water from one place (i.e. from a natural water body) to another place (of use) typically via a canal or pipeline.

water efficiency The accomplishment of a function, task, process or result with the minimal amount of water feasible. It focuses on reducing waste.

water entitlements The right to obtain water established by apportionment institutions. In some places, water entitlements are granted by the state and constitute an informal contract between the state and licence-holders. In other, water entitlements constitute a formal property right with judicial enforcement. Whether formal or informal, the contractual nature of water entitlements adds to the cost of institutional change.

water footprint The total volume of freshwater used to produce the goods and services consumed by an individual or community or produced by a business. The direct water footprint of a consumer or producer (or a group of consumers or producers) refers to the freshwater consumption and pollution that is associated to the water use by the consumer or producer. It is distinct from the indirect water footprint, which refers to the water consumption and pollution that can be associated with the production of the goods and services consumed by the consumer or the inputs used by the producer. The grey water footprint of a product is an indicator of freshwater pollution that can be associated with the production of a product over its full supply chain. It is the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards, calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards.

water harvesting Activities such as forest condensation, fog harvesting, cloud seeding (the dispersal of substances into the air that serve as cloud condensation or ice nuclei, which alter the microphysical processes within the cloud) and direct collection of rainwater related to the increase and capture of precipitation to supplement water supplies.

water infrastructure Physical and organizational structures needed to provide the water quantities and qualities demanded by various water users.

water market The ability to buy, sell or lease water rights, in whole or in part, from one legal entity to another and which involves an exchange of a monetary value.

water productivity The ratio of goods and services produced over the volume of water required for their production; measures the efficient use of water.

water quality The physical, chemical and biological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose.

water reallocation The transfer of water from one use to another.

water reform Measures taken to change current water management practices to provide increased benefits to water users and the environment, typically couched in terms of reducing if not removing inefficiencies, corruption and incompetence.

water renewability The ability of water to be replaced through biological, physical or other natural processes and replenished with the passage of time. Water is renewable through the process of the hydrological cycle.

water resources management The activity of planning, developing, distributing and managing the supply and use of water resources. The development and use of structural and non-structural measures to provide and control natural and human-made water resources systems for beneficial uses.

water security The availability of a reliable and secure access to water over time.

'water sector' Commonly refers to all activities, trade and professional organizations and individuals involved with providing drinking water and wastewater services (including wastewater treatment) to residential, commercial and industrial sectors of the economy.

water service management, delivery, control A water service control system includes an underground water main, at least one water consumer station downstream from the water main, and an underground water delivery channel and valves that control the flow from the water main to the water consumer.

water storage A term used within agriculture to define locations where water is stored for later use.

water stress The symptomatic consequence of water scarcity (physical or economic), which may manifest itself as increasing conflict over sectoral usage, a decline in service levels, crop failure, food insecurity and so forth. It is often measured by the extent of the difference between supply and demand.

water supply and sanitation (WSS) Services typically provided by water utilities to provide the quantities and qualities of water where and when demanded, and to provide the means of wastewater collection, treatment and disposal.

watercourse Any flowing body of water.

water-derived benefit Economic, ecological or social benefit obtained due to the particular use or management of water.

water-related hazard Human health, economic or social hazard resulting due to the excess, shortage or pollution of water.

watershed The area of land where all of the water that is under it or drains off it goes into the same place. Healthy watersheds provide a host of services, including water purification, groundwater and surface flow regulation, erosion control and streambank stabilization.

wetland An area of ground that is saturated with water either permanently or seasonally (swamp, marsh, peatland, shallow lake).

willingness to pay (WTP) The maximum amount a person would be willing to pay, sacrifice or exchange in order to receive a good or to avoid something undesired, such as pollution.

withdrawal The removal of water from some type of source, such as groundwater, for some use by humans. The water that is not consumed is subsequently returned to the environment after use, but the quality of the returned water may not be the same as when it was removed. Withdrawn water can be used (such as for cooling) without being consumed.

yellow water Sanitary wastewater containing only urine.

The purpose of this glossary is to serve as a reference for readers of the United Nations *World Water Development Report* 4. Definitions might differ somewhat from those used in other publications, and they do not represent official definitions of the UN, UN-Water, or contributors to the WWDR4.

The glossary was prepared under the coordination of Daniel P. Loucks, Contributing Lead Author (Part 2).

This glossary draws, sometimes directly, on material available on the following websites:

http://actionaidusa.org http://answers.yahoo.com http://dictionary.cambridge.org http://dictionary.com http://dictionary.reverso.net http://en.wikipedia.org http://encyclopedia2.thefreedictionary.com http://nsidc.org http://orf.od.nih.gov http://science.nasa.gov/earth-science http://thinkquest.org http://waterwiki.net http://wiki.answers.com www.merriam-webster.com www.Africanwater.org www.alcwin.org www.answers.com www.awwa.org www.businessdictionary.com www.cees.iupui.edu www.cglrc.cgiar.org www.cleanenergyprinciples.com www.corix.com www.cpc.noaa.gov www.csiro.au www.dainet.com www.ecosystemvaluation.org www.ecy.wa.gov www.eoearth.org www.epa.gov www.ess.uci.edu www.euroscience.org www.exclusion.net www.fao.org www.fema.gov www.greenfacts.org www.homelandsecuritynewswire.com www.icpdr.org www.investopedia.com www.kmci.org www.ldeo.columbia.edu www.maweb.org www.mbdc.com www.nationsonline.org www.noaa.gov www.nrdc.org www.ofwat.gov www.physicalgeography.net www.ramsar.org www.science20.com www.sswm.info www.thecommonsjournal.org www.thefreedictionary.com www.ucowr.org www.un.org www.unccd.int www.unep.org www.unisdr.org www.usaid.gov www.waterdialogues.org www.webopedia.com www.who.org www.worldbank.org www.wri.org www.wto.org.

It also draws on *Peak Water: Conceptual and Practical Limits to Freshwater Withdrawal and Use* by P. H. Gleick and M. Palaniappan (2010); *The New Slum Dwellers* by M. Davis (2006); the Macmillan Dictionary; and http://www.ce.utexas.edu/prof/mckinney/papers/aral/Aral.pdf.

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WWDR4

The United Nations World Water Assessment Programme (WWAP) is hosted by UNESCO and brings together the work of 28 UN-Water members and partners in the triennial *World Water Development Report* (WWDR).

This flagship report is a comprehensive review that gives an overall picture of the world's freshwater resources. It analyses pressures from decisions that drive demand for water and affect its availability. It offers tools and response options to help leaders in government, the private sector and civil society address current and future challenges. It suggests ways in which institutions can be reformed and their behaviour modified, and explores possible sources of financing for the urgently needed investment in water.

The WWDR4 is a milestone within the WWDR series, reporting directly on regions and highlighting hotspots, and it has been mainstreamed for gender equality. It introduces a thematic approach – 'Managing Water under Uncertainty and Risk' – in the context of a world which is changing faster than ever in often unforeseeable ways, with increasing uncertainties and risks. It highlights that historical experience will no longer be sufficient to approximate the relationship between the quantities of available water and shifting future demands. Like the earlier editions, the WWDR4 also contains country-level case studies describing the progress made in meeting water-related objectives.

The WWDR4 also seeks to show that water has a central role in all aspects of economic development and social welfare, and that concerted action via a collective approach of the water-using sectors is needed to ensure water's many benefits are maximized and shared equitably and that water-related development goals are achieved.

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UN-Water is the United Nations (UN) inter-agency coordination mechanism for all freshwater related issues. It was formally established in 2003 building on a long history of collaboration in the UN family. It currently counts 29 UN Members and 25 other international Partners. UN-Water complements and adds value to existing UN initiatives by facilitating synergies and joint efforts among the implementing agencies. See www.unwater.org

Convention on Biological Diversity

IAEA

IFAD Enabling poor rural people to overcome poverty

unicef

UNITED NATIONS UNCTAD

UNCCD

UNDESA, UNECA, UNECE, UNECLAC, UNESCAP and UNESCWA

UNDP

UNESCO United Nations Educational, Scientific and Cultural Organization

UNEP

United Nations Climate Change Secretariat

UN HABITAT FOR A BETTER URBAN FUTURE

UNHCR The UN Refugee Agency

UNIDO

ISDR International Strategy for Disaster Reduction

UNITED NATIONS UNIVERSITY

THE WORLD BANK

World Health Organization

World Meteorological Organization Weather • Climate • Water

UNWTO

ILO

unitar United Nations Institute for Training and Research

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United Nations Educational, Scientific and Cultural Organization

World Water Assessment Programme

UN WATER