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Coping with water scarcity

An action framework for agriculture and food security

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Coping with water scarcity

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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About this report

The report aims to provide a conceptual framework to address food security under conditions of water scarcity in agriculture. It has been prepared by a team of FAO staff and consultants in the framework of the project "Coping with water scarcity – the role of agriculture", and has been discussed at an Expert Consultation meeting organized in FAO, Rome, during the period 14–16 December 2009 on the same subject. It was subsequently edited and revised, taking account of discussions in the Expert Consultation and materials presented to the meeting.

The purpose of the Expert Consultation was to assist FAO to better design its water scarcity programme. In particular, the experts were requested to provide recommendations on the range of technical and policy options and associated principles that FAO should promote as part of an agricultural response to water scarcity in member countries.

The document offers views on the conceptual framework on which FAO's water scarcity programme should be based, proposes a set of definitions associated with the concept of water scarcity, and indicates the main principles on which FAO should base its action in support to its member countries. At the meeting, experts were requested to review the draft document and provide feedback and recommendations for its finalization. Issues that were addressed in discussions included:

- Water scarcity: agreement on key definitions.
- The conceptualization of water scarcity in ways that are meaningful for policy development and decision-making.
- The quantification of water scarcity.
- Policy and technical response options available to ensure food security in conditions of water scarcity.
- Criteria and principles that should be used to establish priorities for action in response to water scarcity in agriculture and ensure effective and efficient water scarcity coping strategies.

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FAO recently embarked on a long-term partnership with the Government of Italy, which has agreed to fund a modular programme on the theme “Coping with water scarcity – the role of agriculture”. The development of a conceptual framework to address food security under conditions of water scarcity is part of this programme.

This report was prepared by a team from the Land and Water Division of FAO with assistance from several experts. Pasquale Steduto, as leader of the Italian Trust Fund “Coping with Water Scarcity”, lead the initiative and coordinated the preparation of the report. The report was written by Jean-Marc Faurès, Jippe Hoogeveen and Jim Winpenny, in collaboration with Pasquale Steduto and Jacob Burke. Charles Batchelor prepared a background document focusing on water accounting and water audit, which was extensively used in the preparation of this report.

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Executive summary

Simply stated, water scarcity occurs when demand for freshwater exceeds supply in a specified domain.

Water scarcity = an excess of water demand over available supply

This condition arises as consequence of a high rate of aggregate demand from all water-using sectors compared with available supply, under the prevailing institutional arrangements and infrastructural conditions. It is manifested by partial or no satisfaction of expressed demand, economic competition for water quantity or quality, disputes between users, irreversible depletion of groundwater, and negative impacts on the environment.

Water scarcity is both a relative and dynamic concept, and can occur at any level of supply or demand, but it is also a social construct: its causes are all related to human interference with the water cycle. It varies over time as a result of natural hydrological variability, but varies even more so as a function of prevailing economic policy, planning and management approaches. Scarcity can be expected to intensify with most forms of economic development, but, if correctly identified, many of its causes can be predicted, avoided or mitigated.

The three main dimensions that characterize water scarcity are: a physical lack of water availability to satisfy demand; the level of infrastructure development that controls storage, distribution and access; and the institutional capacity to provide the necessary water services.

DRIVING FORCES BEHIND WATER SCARCITY AND THE ROLE OF AGRICULTURE

Unconstrained water use has grown at global level to a rate more than twice the rate of population increase in the 20th century, to the point where reliable water services can no longer be delivered in many regions. Demographic pressures, the rate of economic development, urbanization and pollution are all putting unprecedented pressure on a renewable but finite resource, particularly in semi-arid and arid regions.

Of all economic sectors, agriculture is the sector where water scarcity has the greatest relevance. Currently, agriculture accounts for 70 percent of global freshwater withdrawals, and more than 90 percent of its consumptive use. Under the joint pressure of population growth and changes in dietary habits, food consumption is increasing in most regions of the world. It is expected that by 2050 an additional billion tonne of cereals and 200 million tonnes of meat will need to be produced annually to satisfy growing food demand.

But to what extent is this steady growth in water demand ‘negotiable’? There is a general agreement that water to satisfy basic needs is not – human health requires a minimum level of access to good quality water. Similarly, with the right to food being increasingly recognized, since water as a critical factor in food production, a minimum quantum for subsistence production could be considered non-negotiable. However, domestic water withdrawal represents globally only about 10 percent of all water uses, but has a very low consumption rate – most domestic use is returned to the environment with little evaporative loss even if quality is degraded. By contrast, agricultural use has direct downstream (or down-gradient) consequences since the production of biomass requires huge quantities of water to be transpired. If the water is sourced for irrigation and transpired, this represents a local hydrological loss that reduces availability in the downstream domain. The purpose of this report is to assess the options and scope for adjustment in agricultural water use as a response to water scarcity.

MEASURING WATER SCARCITY: THE HYDROLOGICAL CYCLE

A correct understanding of water scarcity hinges on an understanding of the laws of physics that govern hydrological processes, and the means to allocate and measure use.

1. **Water is a renewable resource**, but patterns vary in space and time.
2. **Water exists in a continuous state flux** in all its phases (solid, liquid, gas) that is driven by energy gradients applying to the physical processes of evaporation, transpiration, condensation, precipitation, infiltration, runoff, subsurface flow, freezing and melting. It is these flows and fluxes, rather than stocks, that should be the focus of planning and management.
3. **A water balance is governed by conservation of mass**, and the rate of water entering a specified domain is equal to the rate of water leaving the same domain with any differences resulting in changes in storage. The linkages between surface water, groundwater, soil moisture content and the process of evapotranspiration are of critical importance, and still inadequately reflected in many water management plans.
4. **All land areas in a river basin are interlinked through water**. Therefore actions in one part of a hydrological system will have impacts on other parts of the system, and for most intents and purposes water is best managed on the basis of hydrographic units.
5. As water use intensifies, **the diluting and cleaning functions of aquatic ecosystems are stretched to their limit, resulting in accumulation of pollutants**.
6. Any desire to maintain a set of **aquatic ecosystem goods and services implies a limitation** in the availability of water for human use in a given domain.
7. **Water accounting**, i.e. the systematic organization and presentation of information relating to the physical volumes and quality of flows (from source to sink) of water in the environment as well as the economic aspects of water supply and use, should therefore be the starting point of any strategy for coping with water scarcity. Water accounting involves a comprehensive view of the water resources and supply systems and how they are related to societal demands and actual use.
8. **Water audits** go one step further, and place water supply and demand in the broader context of governance, institutions, finance, accessibility and uncertainty These are all elements needed to design effective water scarcity coping strategies.

POLICY AND MANAGEMENT OPTIONS

Options to cope with water scarcity can be divided between *supply enhancement* and *demand management*. Supply enhancement includes increased access to conventional water resources, re-use of drainage water and wastewater, inter-basin transfers, desalination, and pollution control. Demand management is defined as a set of actions controlling water demand, either by raising the overall economic efficiency of its use as a natural resource, or by operating intra- and intersectoral re-allocation of water resources. Options to cope with water scarcity in agriculture can be seen as a continuum from the source of water to the end user (the farmer), and beyond, to the consumer of agricultural goods. These options are discussed below. However, it should be stressed that at the level of agricultural water demand commonly observed in food producing countries, supply enhancement and demand management measures are often linked through the hydrological cycle.

SUPPLY ENHANCEMENT

During the twentieth century, large multipurpose dams have served the needs of agriculture, energy and growing cities, and helped protect populations from flood hazards. While potential for further dam development still exists in some regions, most of the suitable dam sites are already in use, and the development of new dams is increasingly questioned in terms of economic, social and environmental considerations.

On-farm water conservation, particularly the adoption of agricultural practices that reduce runoff, to increase the infiltration and storage of water in the soil in rainfed agriculture, is the most relevant local supply enhancement option that farmers have to increase production. On a slightly larger scale, small, decentralized water harvesting and storage systems contribute to increasing water availability and agricultural production at the household and community levels. However, large programmes of small-scale water harvesting, like the watershed management programmes developed in Andhra Pradesh and other parts of India, have shown significant impacts on the catchment's hydrology and downstream water availability.

Groundwater exploitation has grown exponentially in scale and intensity over recent decades. Groundwater's capacity to provide flexible, on-demand water in support of irrigation has been seen as a major advantage by farmers. While intensification of groundwater use has contributed to improved livelihoods of millions of rural people, it has also resulted in long-term aquifer depletion, groundwater pollution and saline intrusion into important coastal aquifers.

The adoption of re-cycling of drainage water and wastewater use in agriculture tends to be positively correlated with water scarcity. Re-use of drainage water is a reality in most large irrigation schemes, in particular in the large rice-based systems of Asia. Of lesser global significance, but locally important, is the re-use of urban wastewater (it is estimated that world-wide some 20 million hectares of agricultural land is irrigated with wastewater). Efforts are needed to better assess re-use and its potential, and promote safe recycling of wastewater in agriculture, in particular in water-scarce areas.

DEMAND MANAGEMENT IN AGRICULTURE

In broad terms, agriculture has three options for managing overall water demand *within* the water domain:

- reduce water losses;
- increase water productivity; and
- water re-allocation.

The first most commonly perceived option is that of increasing the efficiency of water use by reducing water losses in the process of production. Technically, 'water use efficiency' is a dimensionless ratio that can be calculated at any scale, from irrigation system to the point of consumption in the field. It is generally applied to any management that reduces the non-beneficial use of water (i.e. reducing leakage or evaporative losses in water conveyance and application). The second option is increasing crop productivity with respect to water. This involves producing more crop or value per volume of water applied. The third option is to re-allocate water toward higher value uses through intersectoral transfers (transfers to municipal supply, for instance) or intrasectoral transfers by limiting the irrigated harvested area under a particular crop to reduce evapotranspiration or diverting water towards higher value crops.

Clearly there is scope for managing the demand for water in agriculture in time and in space. But excessive emphasis is often placed on the first option, with efforts aimed at reducing water 'losses' within irrigation distribution systems. Two factors limit the scope for and impact of water loss reduction. First, only part of the water 'lost', while withdrawn for *beneficial use* (defined as water that is diverted for purposes that have clear and tangible benefits, such as for household purposes, irrigation, industrial processing and cooling), can be recovered effectively at a reasonable cost. Second, part of the water 'lost' between the source and final user returns to the hydrologic system, either through percolation into the aquifers or as return flow into the river systems. The share of water lost through *non-beneficial consumption*, either through evaporation or through drainage into low quality water bodies or to the sea, varies according to local conditions. A clear understanding of the real potential for reducing water losses is needed to avoid designing costly and ineffective demand management strategies.

In most cases, the single most important avenue for managing water demand in agriculture is through increasing agricultural productivity with respect to water. Increase in crop yields (production per unit of land) is the most important source of crop water productivity increase. Yield increases are made possible through a combination of improved water control, improved land management and agronomic practices. This includes the choice of genetic material, and improved soil fertility management and plant protection. It is important to note that plant breeding and biotechnology can help by increasing the harvestable parts of the biomass, reducing biomass losses through increased resistance to pests and diseases, reducing soil evaporation through vigorous early growth for fast ground cover, and reduced susceptibility to drought. Therefore managing overall demand through a focus on water productivity rather than concentrating on the technical efficiency of water use alone is an important consideration.

If productivity is considered in terms of added value and not production, re-allocating supply from lower value to higher value crops is an obvious choice for farmers seeking to improve income levels. For this to happen, changes are required in both the management and technology associated with irrigation to provide farmers with a much higher level of control of water supply. In addition, shifts to higher value crops also require access to inputs, including seeds, fertilizers and credit, as well as technology and know-how, and reasonable conditions to operate in much more competitive market conditions. However, in practice, very few farmers are able to make this choice since the market for higher value crops is limited compared with the market for staples. Beyond productivity concerns, agricultural water demand can simply be limited or capped. This is a commonly applied measure where the volume of evapotranspiration used in the production of a unit of agricultural output is limited by reducing the area under irrigation.

Understanding the roles, attitudes and strategies of various stakeholders, including relevant institutions, is a key aspect of demand management strategies. Ultimately, it is at the farmer level that most water will be consumed. Their behaviour and their capacity to adapt will be driven by a carefully selected set of incentives that include both structural and institutional changes, improved reliability and increased flexibility of water supply. Farmers' strategies will be driven by water saving only when water availability becomes their main limiting factor. Policies based on systems of water tariffs aiming to reduce agricultural water demand have proved successful in some cases, but require very constraining conditions and are often difficult to enforce. Approaches based on water quotas and water use (or withdrawal) rights have, in most cases, a higher probability of success.

ACTIONS BEYOND THE WATER DOMAIN

The agricultural response to water scarcity lies, at least partially, *outside* of the water domain. To this extent it is possible to recognize other measures that can help manage water demand:

- reduction of losses in the post-harvest value chain;
- reduction in demand for irrigated production through substitution by imports of rainfed staples; and
- reduction of per capita agricultural water demand.

Reduction of losses in the post-harvest value chain

Beyond agricultural production, substantial savings of water can also be obtained by addressing the issues of waste in the food chain, diets, and the role of agricultural trade. Losses and wastages occur all along the food chain, and have been estimated at up to 50 percent of production in developed countries. While part of these losses may be irretrievable, it makes sense to carefully identify the major sources of losses and assess the scope for their reduction.

Reduction of demand for irrigated production through substitution

Options include enhanced production in rainfed agriculture, and imports of food product through international trade.

There are several reasons to consider investing in rainfed agriculture as part of a water scarcity coping strategy, but the opportunities vary greatly from one place to another. In places where climate is conducive to rainfed agriculture, there is high potential to improve productivity where yields are still low, as is the case in many regions of sub-Saharan Africa. Here, a combination of good agricultural practices, upward and downward linkages (access to finance, inputs and markets), and weather insurance schemes can improve agricultural productivity with little impact on water resources.

The issue of trade is particularly relevant in countries where water scarcity limits the capacity of agriculture to satisfy all the needs for other agricultural commodities. The concept of 'virtual water' was developed in the 1990s to indicate that in a reasonably safe and interdependent world, gains in water productivity can be achieved by growing crops in places where climate enables high water productivity at lower cost and trading them to places with lower water productivity. Although rarely expressed in water terms, virtual water trade is already a reality for many water-scarce countries, and is expected to increase in the future.

Reduction of per capita water demand

Finally, increasing consumption of meat and, to a lesser extent, also dairy products translates into increased water consumption, as their production requires large volumes of water. The extent to which societies are willing to modify their diets as part of a larger effort to reduce their environmental *footprint* reaches far beyond water scarcity concerns. Yet, it has implications in terms of national food security and associated water-scarcity coping strategies.

ASSESSING AND COMBINING FOOD SUPPLY OPTIONS THROUGH A COST CURVE APPROACH

In order to guide decision-makers' choices among the range of available options, these options need to be assessed in terms of their effectiveness, cost, and technical, social and environmental feasibility. The political dimension of their choice will also be carefully scrutinized.

The "food supply cost curve" can help to provide insight in the way a country can bridge its food supply gaps in a cost-effective way. The curve ranks food supply options in terms of their cost and provides an easy way of assessing cost-effectiveness in the achievement of food supply objectives. When used at national level, each country will have its own curve, based on current level of intensification, availability of land and water, and level of losses in the food chain. The cost curve provides a simple but powerful method for identifying and ranking options for food production in conditions of water scarcity. Much of the complexity lies in the establishment of the individual cost curves for the different options, which requires a good understanding of the agronomic, hydrological and socio-economic conditions under which improvements will take place.

PRINCIPLES FOR ACTION

The selection of the right range of options will depend on local conditions, and it is unlikely that a single set of options can be designated as the 'optimal' solution. Nor is a particular option to be seen as desirable in all contexts. The choice of 'no action' is not an option under scarcity; it would translate into environmental degradation, sub-optimal use of scarce resources, inequity in access to these resources, and overall negative impacts on the economy and societal well-being. Therefore, rather than attempting to prescribe solutions to water scarcity, it is suggested that policy options and related strategies should be based on a set of generic principles that are valid across socio-economic settings. Six basic principles have been developed, and are presented below.

Knowledge: base strategies on a clear understanding of the causes and effects of water scarcity

Strategies should be based on the best available evidence, and not on hearsay or intuition, and detailed accounting of water supply and demand should be carried out from the onset. The inter-relationship between surface water and groundwater, between upstream and downstream catchments, between quality and volumes, and the importance of water recycling within river basins all have implications in terms of effectiveness of proposed actions. Well intentioned but ill-informed strategies for coping with water scarcity can have significant perverse impacts on the way water is distributed within the river basin, without achieving expected savings.

Impact: assess the full range of benefits and costs and use systematic and comprehensive decision criteria

It might seem obvious that cost-effectiveness should be considered along with equity and collective values when choosing between options. However, past experience shows that cost-benefit analyses have often overlooked or under-estimated the potential negative impact of water development interventions on people or the environment, while overestimating other benefits. In particular, supply enhancement options have often been selected beyond any reasonable analysis, leading to an over-equipped subsector and ‘artificial’ or ‘constructed’ water scarcity. Calculating cost-effectiveness needs to encompass several dimensions. It varies with time, as a result of change in knowledge of social and environmental processes and values, as well as relative changes in added value of different water use sectors. Only a careful analysis of the cost-effectiveness of each option allows for better identifying the most promising sources of gains in water demand management.

Realistic financing mechanisms are required for water initiatives to meet the full costs of water scarcity interventions and programmes. In many cases, this involves putting less emphasis on capital costs of construction and engineering and more emphasis on capacity building, stakeholder-based planning, operation and maintenance, and other long-term institutional support costs.

Capacity: ensure that the right level of water governance and institutional capacity is in place

Disputes between users increase with water scarcity, as does the likelihood of negative impacts on vulnerable social groups and on the environment. As demand management takes increasing importance, much stronger institutions are needed to guarantee equitable distribution of benefits and maintenance of environmental services. Better definition of roles and responsibilities, empowering of local institutions, review of policies, adaptation of laws, and the use of incentive mechanisms become increasingly important as water scarcity progressively builds up. Efforts for a new water management culture are needed, including public awareness campaigns, educational programmes, capacity building and training at all levels, including water users groups. Institutions also need to adapt to approaches where public, private and other operators can carry out management tasks jointly.

Context-specificity: adapt response to local conditions

The response of a country to water scarcity depends on a number of conditions, including local agro-climatic conditions, levels of water scarcity, the role agriculture plays in national economies, and societal values. It will also depend on external factors, including the global trade and cooperation environment, and the prospects for climate change. Further, in view of the rapid changes in the geo-political, societal and environmental fields, what could be considered well adapted today may no longer be so tomorrow, and strategies must be expected to change.

Coherence: ensure policy alignment between water, agriculture and food security

Decisions outside the water domain, such as those determining energy prices, trade agreements, agricultural subsidies and poverty reduction strategies, can all have a major impact on water supply and demand, and therefore on water scarcity. Alignment of the many policies, legislation and fiscal measures that influence water management, service delivery and level of demand is crucial. Agriculture and food security policies are strongly connected to water policies and that degree of connection needs to be appreciated to ensure overall coherence.

Preparedness: anticipate change through robust decision-making and adaptive management

Planning and management systems need to be flexible, adaptive and based on continuous social and institutional learning. Adaptive management recognizes the high level of uncertainty associated with future situations, and places emphasis on flexible planning that allows regular upgrading of plans and activities. Such a level of responsiveness is only possible if information and knowledge are updated, and if monitoring and information management systems continually provide decision-makers with reliable information. There is always the risk that coping strategies will be derailed by external factors, such as climate change, global financial and economic shocks, and shifting international cooperation agreements. Scenario building, as an integral part of strategy development, is one means of identifying and mitigating these risks, and developing robust responses to uncertainty of future situations.

1. Introduction

1.1 THE WATER 'CRISIS'

The latest World Water Development Reports (UN-Water, 2009, 2012) observe how the various global crises reported recently – in climate change, energy, food security, economic recession and financial turbulence – are related to each other and have impacts on water. The Reports remind us that water plays a role in all sectors of the economy and is essential in achieving sustainable development and reaching the Millennium Development Goals (MDG).

As human demand for water increases and competition between water-using sectors intensifies, water scarcity becomes apparent in a variety of forms. However, the interrelationship between local hydrological environments, livelihoods and economic development are often difficult to understand. An objective appraisal of what we mean by 'scarcity' and how we expect water scarcity to affect the rapid social, economic and environmental transitions that we witness today is long overdue. This report takes agricultural water use as a starting point, since this sector will dominate global withdrawals of water for the foreseeable future.

The Comprehensive Assessment of Water Management in Agriculture (CA, 2007) posed the question: Is there enough land, water and human capacity to produce food for a growing population over the next 50 years – or will we 'run out' of water? It answered this question with the following: It is possible to produce the food – but it is probable that today's food production and environmental trends, if continued, will lead to crises in many parts of the world. Only if we act to improve water use in agriculture will we meet the acute freshwater challenges facing humankind over the coming 50 years. Or put another way, *business as usual* is not an option. Real changes are needed in the way in which water is governed and used if transient or long-term crises are to be averted.

There is a widespread perception that water is becoming scarce as a result of trends that are, to some extent, unavoidable, especially population growth and the resulting increased demand for water for food production and domestic, industrial and municipal uses. This leads many to jump to the conclusion that a 'water crisis' is inevitable. Yet, the more predictable challenges (or potential crises) can be largely avoided by adjusting the way in which water is managed and governed (Moriarty, Butterworth and Batchelor, 2004). The scope for water management to contribute effectively to basic human needs and livelihoods is now well documented (CA, 2007; UN-Water, 2009, 2012). However, the right balance of basic measures of water allocation, service provision and management by end users in relation to a variable hydrological cycle and increasingly scarce resource is still hard to define. In short, the behaviour of water users needs to be better attuned to the growing reality of water scarcity.

1.2 AGRICULTURE, WATER AND FOOD SECURITY

Of all sectors of the economy, agriculture is the most sensitive to water scarcity. Although the agricultural sector is sometimes viewed as a 'residual' user of water, after domestic and industrial sectors, it accounts for 70 percent of global freshwater withdrawals, and more than 90 percent of consumptive use. It is also the sector with the largest scope or potential for adjustment.

In most regions of the world, evapotranspiration from irrigated agricultural land is by far the largest consumptive use of water withdrawn for human use. Steadily increasing demand for agricultural products to satisfy the needs of a growing population continues to be the main driver behind agricultural water use. While the world's population growth rate has slowed since the 1980s, population numbers are still growing fast, in particular in developing countries. In addition, steady economic development, in particular in emerging market economies, has translated into demand for a more varied diet, including meat and dairy products, putting additional pressure on water resources (UN-Water, 2012). It is expected that 60 percent more food will be needed between now and 2050 to satisfy the demand of an eventual population of more than 9 billion people. The net result is that agricultural water use is increasing the severity of water scarcity in some areas, and causing water scarcity even in areas that are relatively well endowed with water resources.

Agriculture, and in particular irrigated agriculture, is undergoing rapid changes and facing both old and new challenges. Farmers across the world have to adapt to a world where trade and globalization have rapidly increased interconnection and interdependence between people's production and consumption patterns, and where technological progress has boosted agricultural productivity. The green revolution and subsequent progresses in agronomy have helped agricultural production outpace population growth and feed an ever-increasing number of people with ever more diversified food of increasing quality. But it has also come with a large environmental cost.

There is another side to these trends, however. The absolute number of malnourished people, most of them in rural areas, does not decrease, and agricultural productivity in many developing countries remains low. The possible impact of climate change on water resources and water demand is uncertain, and likewise for the potential impact of bio-energy production on agriculture and food security. The recent surges and increased volatility of food prices since 2007 are a strong warning of the dangers of complacency about long-term food supplies.

Agriculture is both a cause and a victim of water scarcity. Intersectoral competition for water is most obvious in the hinterlands of large urban centres, but water scarcity can arise in all catchments where the intensification of agriculture in headwater areas reduces water supply downstream. Unsustainable groundwater use can have long-term impacts on agricultural production in areas such as South Asia, where a boom in groundwater-based irrigation in the 1980s and 1990s led to a major increase in agricultural production that is now constrained by aquifer depletion. The major worry is that agricultural production will decline in highly populated areas at a time when demand is rising, and the issue of food security is coming to the fore in all regions.

1.3 AIMS AND SCOPE OF THE REPORT

Given the importance of water for agriculture and food production, and the dominant role of agriculture in global water withdrawal, FAO has undertaken a review of its water programme in order to propose a more effective and more strategic response to the growing issue of water scarcity. The programme is bound by the Organization's focus on agricultural and rural livelihoods, and necessarily reflects the specific concerns about food and agriculture of FAO's members. The promotion of realistic and responsible approaches to water management is part of this mission.

The purpose of this report is twofold. First, to define a water accounting framework that allows water scarcity to be interpreted objectively. Second, to indicate where and how agricultural water management can play a more proactive and effective role in response to increasing concerns over global freshwater scarcity.

The discourse surrounding water allocation and environmental regulation is being shaped by several factors: the competition for water as a social and economic input; the need to protect the environment and account for the cost of using natural resources; and recognition of the values of the environmental services that water performs. Agriculture will continue to be the most important user of water in many countries, and needs to be brought into the debate on the basis of a clear framework for discussion of its impact, its legitimate allocation and the appropriate management response to the era of growing water scarcity.

The role of water in agricultural productivity, rural livelihoods and environmental externalities must be correctly analysed through commonly accepted and scientifically robust definitions and water accounting methods. This involves assessing the efficient use of water at field, irrigation scheme and river catchment scales; considering additional dimensions of productivity; and making macro-economic assessments of the water-related agricultural economy contribution to GDP and global trade. The context of these assessments is a continuum from the point of direct water withdrawal to the point of effective consumption in foodstuffs and industrial commodities.

In the recent past, extensive reviews have been made of the main issues related to water in agriculture and response options in terms of policies and management (CA, 2007). However, the priorities for action, modalities of implementation, and the overall framework in which such action should take place remain to be defined.

FAO has recently embarked on a long-term programme on the theme "Coping with water scarcity – the role of agriculture". At an initial stage, the programme deals with the development of a Comprehensive Framework for agricultural response to water scarcity. Through this project, an integrated package of technical and policy tools will be developed and further promoted among FAO member countries. This comprehensive framework should be flexible enough to be adapted in all bio-physical and socio-economic contexts. In subsequent phases the programme will be adapted to the peculiarities of various regions and applied at country level. The aim of this report is to set the stage for the framework within which FAO will develop its water scarcity programme and interact with its members.

2. Defining water scarcity

A comprehensive framework for coping with water scarcity requires a clear and unambiguous definition that stands up to scrutiny and that can be used in both qualitative and quantitative assessments of water scarcity. A wide-ranging literature search resulted in many descriptions of the character of water scarcity, but no single definition could receive unqualified recommendation.

2.1 EXISTING WATER SCARCITY DEFINITIONS

The aim of this section is not to provide an exhaustive review of water scarcity definitions but rather to use a small number that can be used as a starting point for proposing a clear and unambiguous definition of water scarcity. After considering 20 or so definitions of water scarcity, there are three that stand out as being robust and well constructed.

In a position paper prepared for an earlier FAO e-mail conference on water scarcity, Winpenny (1997) defined water scarcity as an imbalance of supply and demand under prevailing institutional arrangements and/or prices; an excess of demand over available supply; a high rate of utilization compared with available supply, especially if the remaining supply potential is difficult or costly to tap. Such a definition has the advantage of having the explicit recognition that water scarcity is a relative concept. Several variations of this definition have been proposed. Abrams (2009), while re-iterating the relative nature of water scarcity, defined it as a concept describing the relationship between demand for water and its availability. He stressed the fact that the demands vary considerably between different countries and regions depending on the sectoral usage of water, and highlighted the fact that it also varies according to local climatic conditions.

Building on the definition proposed by Winpenny (1997), the World Water Development Report (UN-Water, 2006a) defined water scarcity 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 [...], a relative concept [that] 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. Scarcity has various causes, most of which are capable of being remedied or alleviated."

The strengths of this definition include the recognition that water scarcity can occur at any level of supply and demand, that it has various causes, and that it is capable of being remedied or alleviated to a certain extent.

2.2 DEFINITIONS USED IN THIS REPORT

Water scarcity is here defined as a gap between available supply and expressed demand of freshwater in a specified domain, under prevailing institutional arrangements (including both resource 'pricing' and retail charging arrangements) and infrastructural conditions.

Water scarcity = an excess of water demand over available supply

Scarcity is signalled by unsatisfied demand, tensions between users, competition for water, over-extraction of groundwater and insufficient flows to the natural environment.

In this report, the wide combinations of causes of water scarcity are all considered to be related to human interference with the water cycle. Water scarcity is fundamentally dynamic and varies in time as a result of natural hydrological variability, but more so as a function of prevailing economic policy, planning and management approaches and the capacity of societies to anticipate changing levels of supply or demand. Scarcity can result from short-sighted policies, such as the over-allocation of water use licences in a catchment, or the excessive expansion of irrigation areas with free or cheap water for farmers. The problem intensifies with increasing demand by users and with the decreasing availability and quality of the resource. Scarcity can arises in close juxtaposition with water plenty, where there is no legal or institutional arrangement in place to improve access, or if the required infrastructure does not exist or is not functional. If identified correctly, many causes of scarcity can be predicted, avoided and/or mitigated.

Other related terms are used in this report in the following senses (see the glossary in Annex 1 for other definitions):

- Water shortage: a shortage of water supply of an acceptable quality; low levels of water supply at a given place and a given time relative to design supply levels as a result of insufficient water resources, lack of infrastructure or poorly maintained infrastructure; or low levels of water resources as a result of annual or seasonal differences in climate or a range of hydrological or hydro-geological factors. In the sense used in this report, water shortage is an absolute, not a relative, concept.
- Water stress: the symptoms of water scarcity or shortage, e.g. growing conflict between users, and competition for water, declining standards of reliability and service, harvest failures and food insecurity. This term is used to describe a variety of circumstances and causes. Water Stress Indexes have been proposed (see Section 2.4. for further discussion).

2.3 DIMENSIONS OF WATER SCARCITY

The causes of scarcity, as indicated in the chosen definition, may be of a varying nature, requiring specific responses. The Comprehensive Assessment of Water Management in Agriculture (CA, 2007) states that water scarcity is a critical constraint to agriculture in many parts of the world. Based on prior work by Seckler *et al*. (1998), it distinguishes two main types of water scarcity, namely *physical scarcity* and *economic scarcity*.

Physical scarcity is said to occur when there is not enough water to meet all demands, including environmental flows. Symptoms of physical water scarcity are severe environmental degradation, declining groundwater, and water allocations that favour some groups over others.

Economic water scarcity is described as a situation caused by a lack of investment in water, or a lack of human capacity to satisfy the demand for water. Symptoms of economic water scarcity include scant infrastructure development, either small- or large-scale, so that people have trouble getting enough water for agriculture or drinking. Also, the distribution of water may be inequitable, even where infrastructure exists. Much of sub-Saharan Africa is characterized by economic scarcity, so further water development could do much to reduce poverty.

In a recent report on water scarcity in the Middle East, the World Bank (2007) suggests considering three types of water scarcity: scarcity of the physical resource, organizational scarcity, and scarcity of accountability. Organizational scarcity refers to "getting water to the right place at the right time". Accountability refers to governments accountable to their constituencies and service providers to their users (World Bank, 2007). The emphasis on issues that can be broadly considered as *institutional* is representative of the current trends towards increasing attention being given to management, as supply options reach their limits.

Building on these and other approaches, and acknowledging that scarcity is the result of multiple causes, and therefore requires different responses, we propose considering three main *dimensions* of water scarcity, that can be summarized as follows:

- scarcity in availability of water of acceptable quality with respect to aggregated demand, in the simple case of physical water shortage;
- scarcity due to the lack of adequate infrastructure, irrespective of the level of water resources, because of financial , technical or other constraints; and
- scarcity in access to water services, because of the failure of institutions (including legal rights) in place to ensure reliable, secure and equitable supply of water to users. This dimension brings together the organizational and accountability dimensions proposed by the World Bank (2007).

In the last two cases, countries may have a relatively high level of water resources endowment compared with demand, but may be unable to capture and distribute them because of lack of infrastructure, or institutional factors limiting access to water.

2.4 INDICATORS OF WATER SCARCITY

The best-known indicator of national water scarcity is per capita renewable water, where threshold values of 500, 1 000 and 1 700 m^3/person/year are used to distinguish between different levels of water stress (Falkenmark and Widstrand, 1992; UN-Water, 2006b). On this criterion, countries or regions are considered to be facing *absolute water scarcity* if renewable water resources are <500 m^3 per capita, *chronic water shortage* if renewable water resources are between 500 and 1 000 m^3 per capita, and *regular water stress* between 1 000 and 1 700 m^3 per capita (Table 1). This crude approach to measuring water scarcity was primarily based on estimates of the number of people that can reasonably live with a certain unit of water resources (Falkenmark, 1984). This indicator is widely used because it can be easily calculated for every country in the world and for every year, based on water resources data (FAO-AQUASTAT, 2012) and available population data (UN, 2009). Furthermore, population projections, currently extending to the year 2100, also allow for projection of water scarcity levels in the forthcoming decades.

TABLE 1
Conventional definitions of levels of water stress (after Falkenmark and Widstrand, 1992)

Annual renewable freshwater (m^3/pers.yr)	Level of water stress
< 500	Absolute water scarcity
500 – 1 000	Chronic water shortage
1 000 – 1 700	Regular water stress
> 1 700	Occasional or local water stress

Although this measure has its merits, it oversimplifies the water situation of specific countries, ignoring local factors determining access to water, as well as the feasibility of solutions in different locations. It cannot take account of prevailing climatic conditions; inter- and intra-annual variability of water resources; governance; issues of water access, water rights and social exclusion; competition between sectors; potential for recycling of water or development of unconventional water resources; and environmental water requirements, which will vary from region to region (Molle and Mollinga, 2003). Averages at the country level are also not very meaningful, in particular for large countries with strong regional variations. Presentations made to the Expert Consultation by Spain, Tunisia, China and Chile, amongst others, showed a marked scarcity 'gradient' between different regions of the same country.

In an attempt to better capture the relation between supply and demand, the Millennium Development Goals (MDG) water indicator (FAO-AQUASTAT, 2012) purports to measure the level of human pressure on water resources based on the ratio between total water withdrawal by agriculture, cities and industries over total renewable water resources. While such an indicator reflects the balance between supply and demand, it entails computational and conceptual problems, related in part to the reliability of measurement of water withdrawal, issues of double accounting (re-use of drainage water or return flow), the absence of systematic time series of the data needed for long-term monitoring, and difficulties in interpreting trends. Another water stress index, based on "the percentage of water demand that cannot be satisfied without taking measures" (UN-Water, 2006b), was developed in an attempt to focus attention on remedial action and recognize the dynamic nature of water scarcity. While none of these attempts to quantify water scarcity and related water stress are perfect, they reflect the relative nature of water scarcity and offer first-hand assessment of the dimension of the problem at the level of a country or region.

2.5 THE HYDROLOGICAL CYCLE

Water scarcity is closely related to the hydrological cycle and the physical laws that govern hydrological processes. From the water scarcity perspective, six aspects of the hydrological cycle are crucial:

- Water is a renewable resource. Although the amount of precipitation falling on the land surface is highly variable in space in time, rainfall can be relied on to replenish reservoirs, the soil profile and aquifers. So water is unlike other natural resources that can be fully depleted (e.g. oil and gas).
- Water is in a continuous state of flux. It is constantly moving and changing phase, through processes of evaporation, transpiration, condensation, precipitation, infiltration, runoff, subsurface flow, freezing and melting. In so doing, water has the ability to change state and become a liquid, a gas or a solid (i.e. ice) as it moves through the hydrological cycle.
- Water balance is governed by conservation of mass. The mass of water in the hydrological cycle is essentially constant as is the amount of water in each of the main reservoirs of the water cycle. In other words, water is not created or destroyed in any of the natural processes of the hydrological cycle. This means that the rate of water entering a specified domain should be equal, on average over time, to the rate of water leaving the same domain, with any differences being a result of changes in storage, such as in aquifers, the soil profile or reservoirs. There is therefore only one resource, and only a systemic approach to water can ensure a coherent outcome of any management strategy. In particular, the inter-linkages between surface water, groundwater, soil moisture content and the process of evapotranspiration are of critical importance, and are not fully reflected in many national water management plans. Groundwater and

surface water are ultimately part of the same resource, and cannot be regarded as alternative sources. Attempts to increase the efficiency of water use in a specific domain without a clear understanding of the impact on systemic water balances may lead to unexpected and undesired results. For example, groundwater capture in alluvial plains can easily reduce base flows in rivers.

- Boundaries and river basin linkages. Land and water management in one part of a hydrological system (catchment, aquifer) will have impacts on other parts of the system. For example, intensifying agricultural water use in the headwaters of a river basin can affect both surface water and groundwater availability in downstream areas. A clear understanding of river basin processes is the basis on which the integrated water resources management (IWRM) concept is built. As recognized in the first Dublin Principle (GWP, 2009), a rapidly growing body of practice accepts that water should be managed on the basis of hydrographical units (basins, catchments and, less commonly, aquifers), though these seldom coincide with the boundaries of institutional and administrative units. Water allocation for many uses is normally planned and managed though administrative units such as provinces, municipalities, districts or irrigation schemes. An important challenge is to ensure proper linkages across different boundaries. Water for irrigation or urban use – particularly where large inter-basin transfers are involved – will often be used in a different hydrographical unit to the one in which it was sourced. Catchments and aquifers often cross international borders. From a water accounting perspective, boundary issues are a fact of life that has to be acknowledged.
- The limits of cleansing and dilution of pollutants. Until quite recently, many cities, even in the developed world, relied on the self-cleansing and dilution potential of rivers and coastal waters when disposing of effluent from towns and cities. This was able to continue as long as the densities of populations and related industries were low. However, with the growth of understanding about the impact of untreated effluent on riverine and coastal ecology (and eventually people), it is apparent that the diluting functions of aquatic ecosystems have reached their limits in many places and that such practices now need to be carefully regulated. Wherever regulations are lacking or poorly enforced, the pollution of water sources can aggravate water scarcity.
- Maintenance of aquatic ecosystem goods and services. Aquatic ecosystems, including many rare and important habitats, depend on the maintenance of groundwater levels and flow regimes in river systems. Environmental requirements are now being clearly identified in water resource accounts whereas in the past they have tended to be ignored or regarded as residual claimants on water. Globally, the results of this attitude are all too evident. The conceptual framework proposed here suggests that the environment should not be considered as a competitor for water with other uses. Instead, the preservation of environmental functions is a pre-condition for maintaining supplies for other purposes. While preserving the environmental function of water systems is a priority, its execution will involve careful negotiation on required environmental flows. Furthermore, since agricultural landscapes also perform environmental functions, the boundary between environmental water requirements and agricultural water demand is often not clear cut.

3. Driving forces behind water scarcity

The drivers of the perceived water crisis are well known: global water use has been growing at more than twice the rate of population increase in the last century, and an increasing number of regions are reaching the limit at which reliable water services can be delivered. Demographic growth, economic development, urbanization and pollution are putting unprecedented pressure on renewable water resources, especially in semi-arid and arid regions. In parallel, there is increasing recognition that environmental services and ecosystem functions should no longer be treated as residual water uses. Climate change and bio-energy demands give a further twist to the already complex relationship between development and water demand.

The causes of water scarcity are many and interrelated (Abrams, 2009). Scarcity arises when demand grows beyond available supply, whether supply is limited by uncoordinated planning and inadequate hydraulic infrastructure or by the physical availability of water itself. It grows worse as competition for water increases, and individuals or groups are driven to capture increasingly scarce resources (e.g. through competitive well deepening or speculation in water rights).

Over-development of hydraulic infrastructure is a main cause of constructed water scarcity (Molle, 2008). In many river basins, the expansion of irrigated areas has boosted demand beyond the capacity of catchments, stretched available resources and progressively generated water scarcity. In years with low rainfall, the water demand that has been allowed to build up during wet years cannot be satisfied, leading to a general perception of water scarcity and generating calls for additional investments in water saving technologies. Wet years, instead, are seen as lost opportunities, when 'excess' water flows to the sea, and this too often translates into new water development. Research has shown that over-development of infrastructure and growing artificial scarcity often results from an alliance of financial and political interests rather than from any legitimate 'need' (Molle, 2008). The pressure to 'save' any single drop of water from 'running to the sea' is often politically stronger than any carefully conducted hydrological assessment that would take into account the economic, environmental and social dimensions of water resources development.

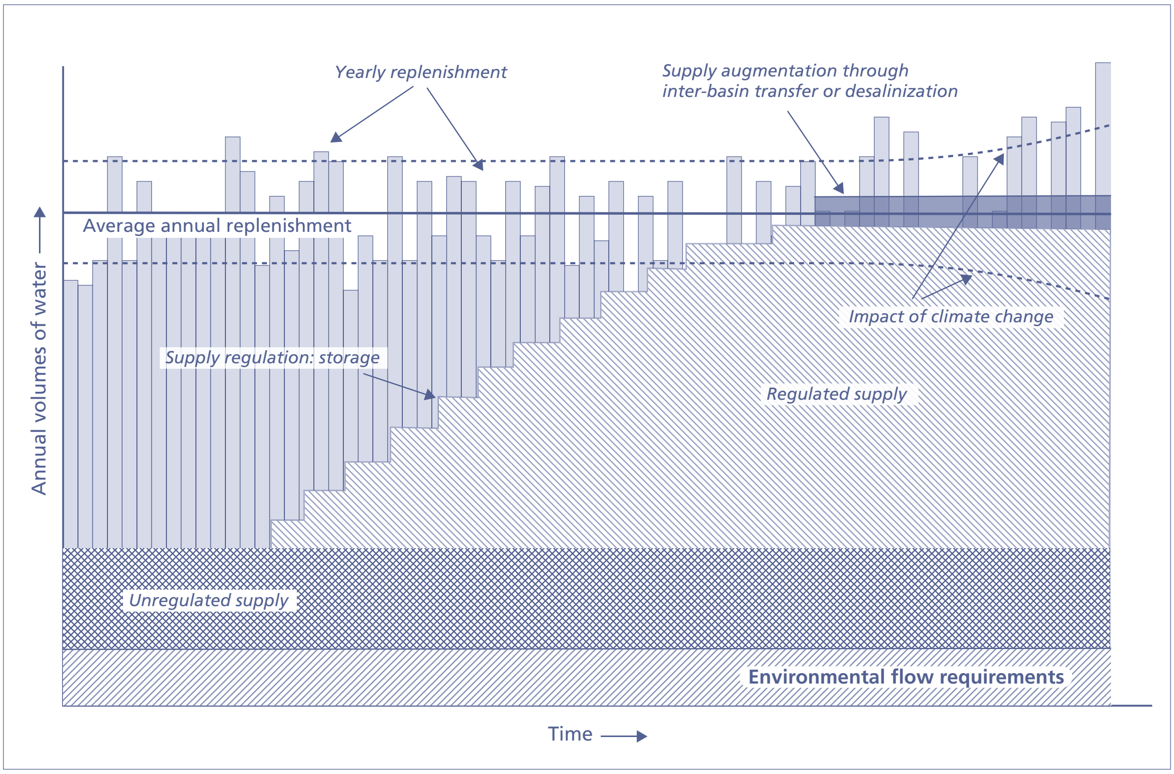
In some regions, excessively optimistic estimates of available water resources and subsequent over-allocation of water rights has caused serious shortages during drought periods. In Australia, the average inflows to the Murray-Darling river system during 2001/2–2009 was only 33% of the average over the previous 100 years – which had been the basis used for the existing system of allocation. Future climate change is likely to further invalidate the hydrological assumptions on which current rights were issued. The Colorado River in the southwestern United States is another case of over-allocated water, in this instance driven by the growth of demand and the increasing claims of the environment (especially the US Endangered Species Act)[1].

3.1 FACTORS AFFECTING WATER SUPPLY

Several factors affect the annual available supply of water (Figure 1). They can be of natural or anthropogenic nature. The annual volumes of flow, their distribution in

1 Information from the presentations by Australia and the USA at the Expert Consultation.

FIGURE 1
Factors affecting water availability



time and space, and inter-annual variability depend on climatic and geomorphological conditions. The geological conditions further determine the characteristics of groundwater recharge and storage. The availability of water is much less than the total water flowing in a system. It fluctuates from year to year, and only part of it is accessible for human use as a reliable source of constant supply.

The inter-annual variability of rainfall translates into variability in river runoff and aquifer recharge, the two main sources of water. Water is unevenly distributed over time and space, and a large proportion of global water resources is available far away from population centres, or in places where demand is low. Since precipitation is also uneven over time, peak runoff may occur during the season of the year that coincides with the lowest water demand, in particular for agriculture (though this is not the case when rivers are fed by glaciers that melt in spring).

Anthropogenic interventions can increase the volumes of water available for use. Water control, through the construction of reservoirs, decreases exposure to seasonal or inter-annual variations of flows and increases the volumes of water available on a regular basis. Water storage development basically involves transferring water from high-precipitation regions to low-precipitation regions. In the past, the most obvious and most common response to this problem has been to store surface water behind dams, but underground water storage has been increasingly resorted to as a convenient alternative in recent decades.

Supply enhancement can also be obtained through import of freshwater into a given system or basin. Inter-basin transfers, desalinization of sea water, where it is possible, and the direct use of wastewater are the most important ways of supplementing natural supply through import of water from outside of the system. Other, more marginal options to increase supply include the transportation of water by tankers or bags by sea. These are usually expensive options that are considered as short-term emergency solutions and usually strictly limited to the satisfaction of basic domestic needs.

Water quality is also relevant in this context. As a result of the increasing re-use and recirculation of water, which is in itself a response to water scarcity, water quality tends to deteriorate, thus reducing the availability of water of sufficient quality for given uses. In some regions, there is also the problem of natural contaminants such as fluoride and arsenic linked to groundwater overdraft, which are therefore both a cause and a result of water scarcity. The deterioration of water quality may therefore make scarcity worse, and damage economic growth. The mindset used in water resources management needs to become more circular, and less linear, in order to take on board water (and nutrient) recycling, and consider pollution control as an important element of water supply management strategies.

Environmental flow is a term used to describe the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these (Brisbane Declaration, 2007). The condition in which aquatic ecosystems and their services must be maintained is a decision with both technical and socio-political dimensions, requiring an understanding of biophysical processes as well as social values specific to each time, location and economic circumstance. The desired ecosystem conditions may be specified by national legislation or international conventions, with implications for the water regime needed to maintain the ecosystems in these conditions. Alternatively, the environmental flow allocated to a river system may be negotiated between water users, with the ecosystem condition the outcome of these deals. In either case, maintaining a prescribed regime of environmental flows may reduce the amount of water available for withdrawal upstream or transfer availability downstream.

Climate change is expected to alter hydrological regimes and the availability of freshwater, with impacts on both rainfed and irrigated agriculture (UN-Water, 2009, 2012; FAO, 2008; FAO, 2011a). Projections show a general reduction in precipitation in semi-arid areas, an increase in precipitation in temperate zones, higher variability in rainfall distribution, an increase in the frequency of extreme events, and an increase in temperature. All these effects will have a particular impact on tropical and sub-tropical agriculture (IPCC, 2008). A severe reduction in river runoff and aquifer recharge is expected to occur in the entire Mediterranean basin, as well as the semi-arid areas of southern Africa, Australia and the Americas, affecting the availability of water for all uses.

Changes in runoff affecting the availability of water, either in rivers or for aquifer recharge, will add to human pressure on water resources. A combination of reduced river base flows, flooding and rising sea levels are predicted to affect highly productive irrigated systems dependent upon glacier melt (e.g. Punjab, Colorado) and lowland deltas (e.g. the Indus, Nile, and Brahmaputra-Ganges-Meghna – the world's most densely populated delta). In the semi-arid tropics, where increased occurrence of droughts and floods is predicted, climate change is expected to affect the rural poor in particular, by reducing crop and livestock yields (IPCC, 2007).

3.2 FACTORS AFFECTING WATER DEMAND

Factors affecting water demand are all anthropogenic by nature. Population, its growth rate and changes in consumption patterns directly affect demand for goods and services, and the water associated with their production, processing and delivery. Water use sectors are conventionally organized into agricultural, industrial (including evaporated cooling water) and municipal (including domestic). Recreational uses, hydropower generation and environmental flows are generally considered to be non-consumptive users, except when extensive open water evaporation result from in-stream storage. Population also affects water resources indirectly through changes in land use and water use patterns, with significant implications at local, regional and global levels (UN-Water, 2009).

Human pressure on water resources increases as their incomes grow. This applies not just to household water demand (as people use more water for bathing, washing and gardening), but also to municipal demand (including irrigation of parks and golf courses, as well as the supply of water for tourism and recreation) and the growth in demand for industrial and agricultural products. Economic growth is accompanied by increased consumption of manufactured goods, electric power, services, etc., all of which raise the demand for water. This growth is not irrevocable, and eventually reaches its peak at a certain income level, or varies according to the level of environmental consciousness. In the United States, total water withdraws peaked in the early 1980s, despite more recent population growth. Per capita water withdrawals have been declining steadily since the late 1970s [2].

Increasing incomes lead to a rise in the per capita demand for food. As people diversify their diets, they eat more meat and dairy products, the production of which requires more water than a diet based on staple crop products (cereals or root crops). Per capita food consumption is increasing on average in most regions of the world. It is expected that the global average food supply will rise from 2650 kcal/person/day in 2006 to above 3 000 kcal/person/day in 2050. These per-capita figures include post-harvest production losses and food waste, and translate into an additional billion tonne of cereals and 200 million tonnes of meat to be produced annually (FAO, 2006a; Bruinsma, 2009).

Urbanization also affects food consumption. In cities, supermarkets, restaurants and convenience food (commercially prepared food designed for ease of consumption) become more important. One consequence of this is that the length of the food chain increases, resulting in more food wastage. Taking these factors into account, FAO estimates that global agricultural production would need to grow by 60 percent between 2006 and 2050 to keep up with food demand (Bruinsma, 2009). It is expected that both the proportion of cropland under irrigation and the share of irrigated production will increase, resulting in greater demand for agricultural water (Bruinsma, 2009).

Other emerging trends will be important in shaping the demand for agricultural water. The production of bio-ethanol tripled between 2000 and 2007 (OECD/FAO, 2008), while biodiesel production increased elevenfold. The potential impact of biofuel production on water resources varies with local agroclimatic conditions and policies. It is greatest where agricultural production depends on irrigation. In rainfed areas it is much more indirect and difficult to assess. Where water supply is limited, the increased production of biofuel could result in reduced water allocation to other crops or uses. Although biofuels currently account for only a few percentage points of total water use at global level, their impacts – particularly on water quality as a result of intensification – could become large for some countries, including China, India and some regions of the United States of America.

2 Information from the presentation by the USA at the Expert Consultation.

Climate change will affect agricultural water demand and as a result will alter the global distribution of agriculture. More frequent and severe droughts and floods will hurt local production, especially in subsistence sectors at low latitudes and in key food-insecure areas dominated by rainfed agriculture. This will accentuate demand in global markets and put further pressure on irrigated production. Rising temperatures, along with shifts in hydrological regimes of major rivers, will have substantial impacts on agricultural water demand.

The extent to which water demand is 'negotiable' is central to coping strategies for water scarcity. Water to satisfy basic needs such as drinking, sanitation and hygiene is effectively non-negotiable, but it represents only a small percentage of water demand. In a similar vein, the right to food concept is increasingly recognized. The production of food requires huge quantities of water, determined by the fundamental biophysical processes associated with food production. There is therefore a non-negotiable volume of water needed to ensure safe and sufficient food for everyone (Steduto, Hsiao and Fereres, 2007). Despite this, sizeable changes are possible in the way water is used to produce food. For instance, the choice of crop type cultivated under irrigated or rainfed circumstances, the number and type of animals to be raised, farming practices and irrigation technologies in combination with their associated productivity levels, changes in the spatial distribution of production (implying trade), and changes in social habits (consumption and distribution of food, diets) can all reduce the overall demand for agricultural water and offer room for manoeuvre. They are the subject of this document and are discussed in greater details in Section 6.

4. Coping with water scarcity: the conceptual framework

4.1 BUILDING ON EARLIER WORK

The literature provides examples of attempts to conceptualize the different phases of water resources development and management in response to water scarcity. These frameworks have been developed to reflect a relative emphasis on one or another element of the supply–demand balance. The frameworks described below have all been designed to address water scarcity in conditions where irrigated agriculture represents an important part of the demand for water.

Most frameworks propose a sequential or step-wise approach to water scarcity. Keller, Keller and Davids (1998) and Keller (2000) suggested distinguishing three phases of river-basin development: exploitation, conservation and augmentation.

Typically, the exploitation phase would be dominated in early stages by direct surface diversion and the use of shallow groundwater, complemented, at a later stage, with progressive building of storage and water distribution, and the drilling of deep tubewells. During the conservation phase, demand management and efforts towards efficiency increase would become more important followed by more systematic water treatment and reclamation and salt disposal. The augmentation phase would focus on water transfer from distant basins and on seawater desalinization, allowing annual supply to expand beyond average annual renewable supply. While such description applies well to many of the regions that have benefited from the green revolution in the 1960s and 1970s, in particular countries like India and Pakistan, it might not be necessarily valid in other places or at other times.

Molden, Sakthivadivel and Keller (2001) proposed a different series: development, utilization and allocation, as follows:

- First, river basin development: dams are constructed in the most convenient locations, water resources are sufficient to satisfy demand from all sectors of the economy, and water quality and ecosystems are only affected to a minor extent. This phase is comparable to the exploitation phase as distinguished by Keller, Keller and Davids (1998).
- Second, utilization or conservation: water shortages begin to appear and competition for water emerges between the different sectors and within sectors. Water quality deteriorates and aquatic ecosystems are damaged, due to both reduced water quality and quantity. Water policies focus on improving water management and conservation, the keywords being modernization, performance and productivity enhancement. At the same time, water pollution and groundwater withdrawals call for better and more effective regulation.
- Third, re-allocation: water has become a rare commodity and is no longer sufficient to satisfy the aggregated demand from all sectors. Policies are directed towards the economic optimization of water, with emphasis on re-allocation of water from low value to high value uses. For this third phase, Keller, Keller and Davids (1998) focus on augmentation, such as through inter-basin transfer or desalination, rather than re-allocation.

The three steps described above – broadly development; conservation; and re-allocation or augmentation – are neither watertight nor are they mutually exclusive at any particular time. Because of the interconnectedness of users throughout the hydrological cycle (particularly links between upstream and downstream, and surface water vs groundwater systems) they may not be wholly additive. There are various examples of this point: augmentation projects that have the side effect of reducing supply to some users (thus effectively becoming re-allocation); 'conservation' measures that effectively guarantee supplies to one user while reducing reliability to others; development of groundwater reserves, which reduces supply of surface water ('re-allocation' again); etc.

Pursuing a more analytical approach, Molle (2003) proposes that policy responses to scarcity should be considered in a wider political economy framework. Sequential models of basin development such as those mentioned above tend to be based on economic rationality or concepts of social adaptation that may be too restrictive. Societal responses to water scarcity are not driven solely by economic considerations or locally perceived needs, but result from the distribution of power among stakeholders, as well as their respective interests and strategies with regard to the different options available.

Molle (2003) suggests replacing the sequential approach with one that recognizes that all strategies tend to be pursued in parallel when scarcity becomes severe. In reality, it may be more useful to regard the various response options as a menu to be drawn upon according to local circumstances. Objective criteria such as benefit-cost analysis and cost-effectiveness analysis can help these decisions, but they will always be taken in a political economy framework. To complicate matters, the response options are often interdependent, and come in 'packages'. The experience of countries taking part in the Expert Consultation shows that, even though there is a broad progression from supply enhancement to demand management and re-allocation as scarcity worsens, there is also a great deal of overlap, and at any one time a range of measures is being implemented.

4.2 OPTIONS TO RESPOND TO WATER SCARCITY BY MAJOR POLICY DOMAIN

There is a key difference between responses by the state at national level and the local response of small groups or communities. These two types of responses are interdependent, but while emphasis is often placed on state policies, adjustments made by local farmers are crucial in shaping the demand for water from agriculture and its impact on the hydrological cycle. Elements like the nature of the state and state–citizen relationships, the impact of 'shock events', the nature of the political economy and the conditions of agrarian change are crucial in shaping the responses to water scarcity (Molle, 2003). In this context, it is important to consider that water scarcity is perceived differently by different categories of stakeholders, who develop different adaptation and coping strategies as a function of their power and capacities.

The United States of America and Australia illustrate the dynamic interplay between federal and state powers as water scarcity intensifies. In the United States of America, water governance is primarily a state responsibility, but some federal legislation is of overriding importance, and the Endangered Species Act has become the dominant federal influence on all water withdrawals. This is a major influence on public responses to water scarcity, especially in the arid western states. In Australia, the exceptional drought of the last decade has caused the federal government to intervene and modify powers exercised by the autonomous Murray Darling Basin Authority [3].

3 Information from the presentation by the USA at the Expert Consultation.

Figure 2 is an attempt to capture these different dimensions of the problem, and to acknowledge the broader environment in which a decision takes place. The supply- and demand-side options are by and large located at the level of technical planning and investment economics, but they are widely influenced by the overall context of governance, institutional framework and the policy environment. These dimensions are discussed in more detail in Section 6.

FIGURE 2
Placing water scarcity response options within a broader policy context

Table 2 presents options by major policy domain: water, agriculture and national food security. The taxonomy distinguishes between two broad categories of options: those dealing with *supply enhancement*, and those dealing with *demand management*. This broad division is retained in the rest of this report.

The table sets out three domains in which supply enhancement and demand management can be applied. Firstly, there is water in its broadest sense, with development and management of the resource to the benefit of users in all sectors, including the environment. Secondly, there is agriculture – the specific concern of this report and a major water user. Finally there is the realm of food self-sufficiency and national food security, with implications for a country's international trade as well as consumption habits and the organization of its food industry.

TABLE 2
Water scarcity response options by major policy domain

Major policy domain	Supply enhancement	Demand management
Water	River diversion; dams; groundwater development; desalinization; pollution control	Intersectoral allocation; increase in the overall efficiency of sectoral water use
Agriculture	On-farm storage; groundwater development; re-use and recycling	Increase in crop productivity; reduction in losses; restraining the cropped area under irrigation; intrasectoral allocation (shifting to higher value production)
National food security	Food imports, storage, distribution efficiency	Reduction in waste in the food chain; changes in dietary habits

Supply enhancement includes increased access to conventional water resources through the construction of hydraulic structures aiming at regulating water supply and conveying water to the end user (dams and reservoirs; conveyance systems), as well as enhancing supply with treated wastewater, desalination and inter-basin transfers. Pollution control should also be considered a supply management option, as it increases the amount of water available for beneficial use, as well as for inter-basin transfer.

Demand management, in contrast, aims to raise the overall economic efficiency of water use, or to re-allocate water within and between sectors. The general aim of demand management is to maximize the benefits obtained from a given amount of water available to users, which could also include producing the same benefits from less water. In agriculture this might involve producing more highly valued crops from irrigation, or raising crop productivity, or reducing the consumptive use of water by minimizing evapotranspiration, or restraining the cropped area under irrigation. Demand management options are usually more difficult and less popular to implement than supply enhancement options. This is the reason why they are often considered in a second stage, after the easier supply-side options have been implemented (Molden *et al.*, 2010).

Improvements in the technical efficiency of distribution of water can be regarded either as a supply-side or a demand management measure, depending on the nature and scale of the action, and where responsibility lies. Major improvements to canals and pipelines, for instance, can be regarded both as supply-side measures (as they increase water available to users) and as demand-side measures (as they reduce evaporation losses and leakages), whereas local and on-farm improvements, particularly those under the control of farmers themselves, are more akin to demand management, since they affect the economic efficiency with which the water is used.

4.3 A DYNAMIC MODEL OF POLICY RESPONSES

Figure 3 illustrates a common pattern of response to the growth of water scarcity, which can be observed in many regions. In the first stages of water scarcity, water demand can be met relatively easily through river diversion, or by increasing storage through building dams and tanks, or installing tubewells to pump groundwater. At a later stage, the overall economic efficiency of water use is addressed. In agriculture this can be done through better crop and water management and the modernization of irrigation infrastructure. Over time, measures to enhance supply through the more systematic re-use of wastewater also become important. As demand is increasingly limited by available supply, allocation policies become more prominent. National food security may have to be modified to allow more imports of agricultural products, where there is not enough water for agricultural self-sufficiency.

Eventually, other, more costly, forms of supply enhancement, e.g. desalination, may become feasible. The pressure will mount on agriculture to increase its water productivity not only through more technically efficient use of water but also through a shift towards higher value crops in order to optimize the economic return from irrigation water.

FIGURE 3
Coping with water scarcity: a stylized sequence of the relative demand for water by different sectors and response options over time

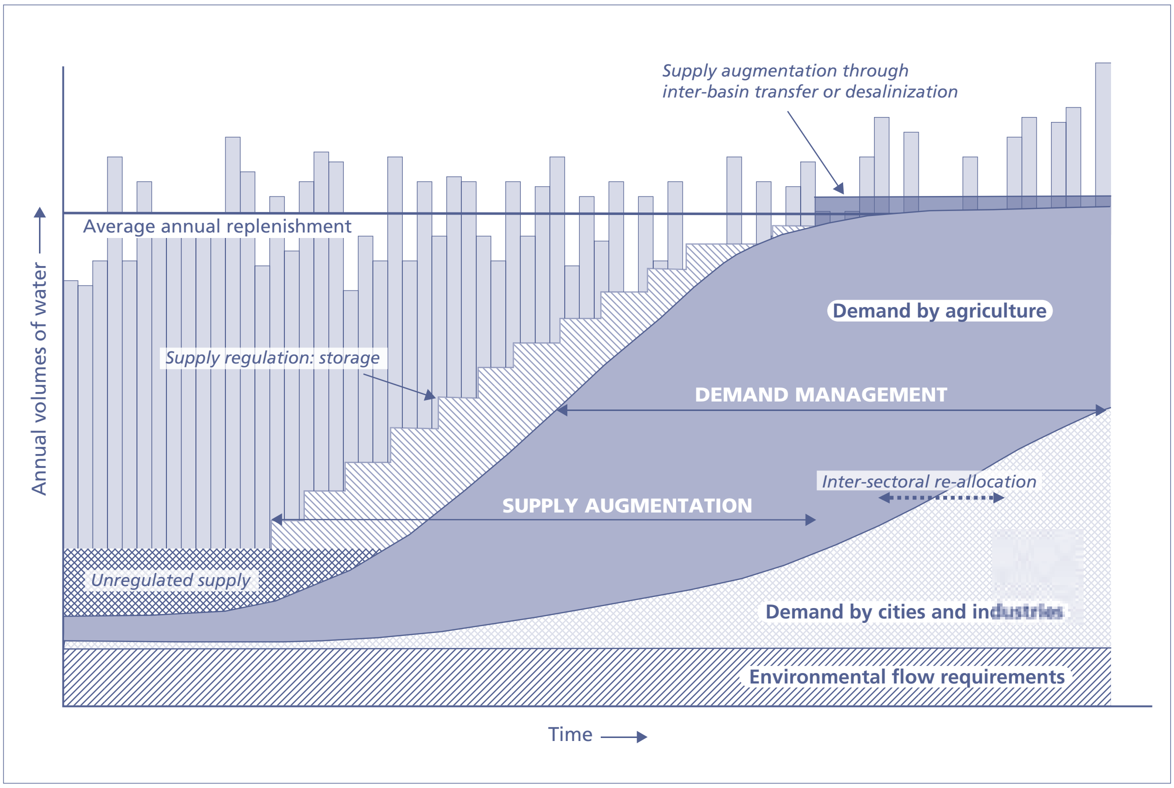
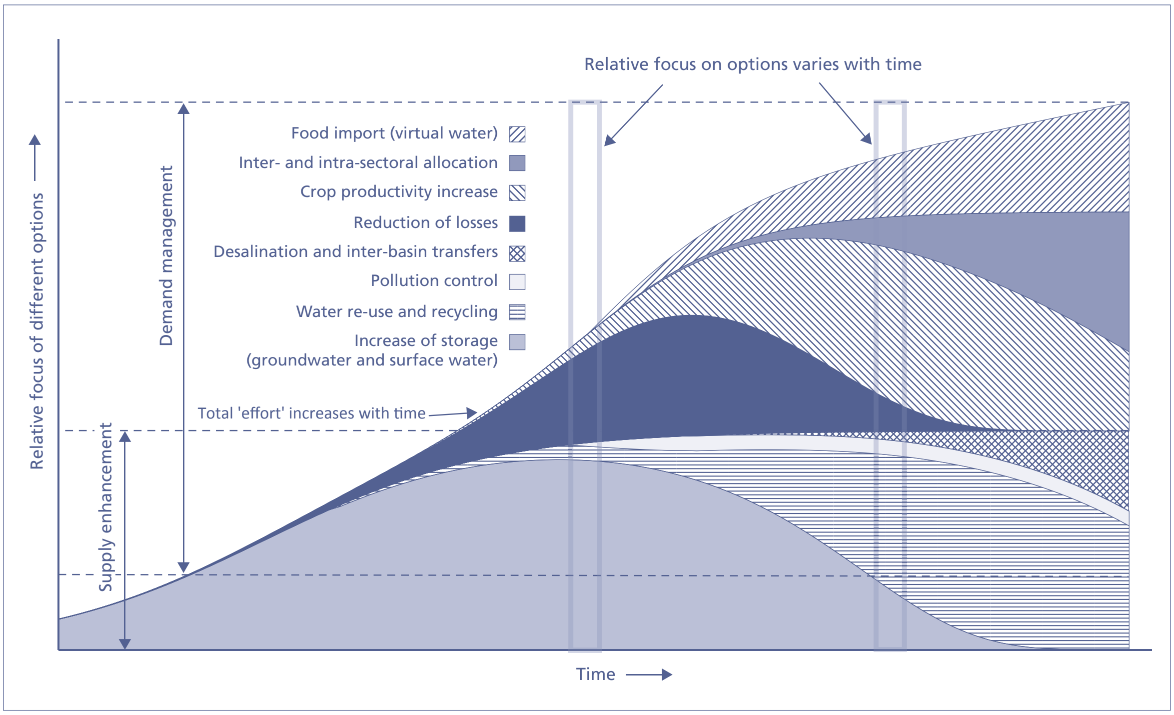


Figure 4 shows in a schematic way the relative distribution of focus on different supply and demand options over time. Clearly, the shape of the curves, the sequencing of the options and the relative importance and relevance of the different options will vary according to prevailing agro-climatic, socio-economic and market conditions, as well as the policies and strategies chosen. The figure does not necessarily imply that this is an 'optimal' or 'efficient' bundle and sequence of measures, nor a model to follow in every case. Rather, its purpose is to illustrate the variety of options available and the way they might evolve over time.

4.4 AGRICULTURAL RESPONSE TO WATER SCARCITY

Farmers are typically very adaptable to changes in market opportunities and access to productive inputs including water (Shah, 2009). The successful response of agriculture to fast population increase in the second half of the last century and to progressive shortage of land and water are a case in point: over the past 30 years, the world's total agricultural production doubled, while the expansion of cultivated land was only about 15 percent and all of this growth occurred in land equipped for irrigation. In regions of land scarcity, such as South Asia, the growth in commodity production was almost completely based on increases in yields and cropping intensities. In contrast, in South America, the pressure on land is less, and 40 percent of the growth in production was due to an areal increase in farmed land. Adaptation is evident in water-scarce regions such as the Near East and North Africa, where irrigation efficiencies are often 20 percent higher than in water-rich areas of Southeast Asia, Latin America or sub-Saharan Africa.

FIGURE 4
A schematic representation of the relative focus on different options for the agricultural sector to cope with increasing levels of water scarcity over time



In early stages of water development, when water supply can easily satisfy demand, priority is usually given to supply management through the construction of storage and conveyance infrastructure in support of irrigation development. Later, when the supply of water no longer satisfies unrestricted demand and the low-cost gains in efficiency have already been made, efforts focus on demand management: increasing the productivity of water in agriculture and reducing losses are obtained through management and technical measures that can help to offset supply limitations (Loeve *et al.*, 2004).

As scarcity increases, the combination of forces that drive demand for water often lead to a fall in both the share and absolute allocation of water to agriculture. This outcome reflects the priority given to water supply for domestic uses in fast growing urban areas. In many situations, preference is also given to industrial users over agriculture, both through regular allocation processes or, in emergencies, by direct appropriation. The increasing recognition of the need to reserve water for the functioning of ecosystems is a further challenge for agriculture in water-scarce areas (CA, 2007).

In negotiating its legitimate share of water, agriculture can invoke the multiple functions it performs, which go beyond commodity production and deliver important social and environmental benefits. Nevertheless, agriculture must be able to show more productive use of its water, and for this to happen, sizeable investment will be needed, which farmers will only do if it is profitable.

One eventual outcome of increased competition for scarce water resources, of relevance to national food security, is when agriculture is no longer able to satisfy national demand, and additional demand for agricultural products (including food) must be met through imports. Importing agricultural produce in a water context is often referred to as importing ‘virtual water’. According to Molle (2003), importing virtual water can be considered as the ultimate case of supply management since the amount of water available is 'augmented' by the amount embodied in imports, which would otherwise be withdrawn by agriculture. From another viewpoint, at a macro-economic level, the import of virtual water is an efficiency gain since the water that would otherwise be used in agriculture is released for potentially more productive use, and therefore it can be considered as a demand management measure.

Tunisia illustrates a progression that began with supply enhancement measures: large dams, small earth dams, mixing fresh water with wastewater, water transfers from inland to coastal areas, and desalination of brackish water for domestic use. Over the last 15 years this has been complemented by programmes on the demand side: modernization of irrigation systems, backed by subsidies, re-allocation of land and water to 'strategic crops', a halt to the production of sugar beet, and the promotion of inter-cropping trees with crops by small-scale farmers. In Spain, current measures are a mix of supply-side programmes for wastewater re-use, desalination and on-farm and district storage, with demand management actions on the modernization of irrigation to improve service levels and the re-allocation of water to high-value crops. The South African strategy to address water scarcity in agriculture includes the promotion of water user associations, licensing reforms, encouragement of efficient use of water, the control of invasive alien vegetation (e.g. eucalyptus growing along river banks) and water pricing[4].

4 Information from the presentation by South Africa at the Expert Consultation.

5. Water accounting: getting the water budget right

Any strategy aiming at addressing the challenge of water scarcity must be based on a thorough understanding of the elements of the water balance, including supply and demand for water and the spatial and temporal dimensions associate with it. Water accounting refers to the systematic study of the hydrological cycle and the current status and future trends in both water supply and demand. Beyond the simple accounting of volumes and flows, it also focuses on issues relating to accessibility, uncertainty and governance.

5.1 TRANSPARENT WATER ACCOUNTING

The main purpose of water accounting is to help societies to understand their water endowment: how much water there is, where it is, how it is used, and whether current patterns of use are sustainable in future. In its popular meaning, accounting means reporting on stewardship, in this case societal use of its water resource. Thus water accounting starts with measurement, but is unavoidably drawn into questions of water use and its governance.

No coping strategy will be effective if not based on clear understanding of the hydrological cycle and sound water accounting. Water accounting is being increasingly promoted as a key component of programmes of *integrated water resource management*. It can be a one-off activity designed to achieve a specific purpose, or it can be part of a long-term monitoring and evaluation programme aimed at improving and sustaining water services delivery. Information collected during water accounting is typically very varied and addresses a range of societal, technical and governance issues.

Water accounting is a vital component of any policies and programmes aimed at tackling water scarcity. The reason being that water scarcity is a relative concept (i.e. an excess in water demand over available water resources in a specified domain). Hence, water scarcity can only be described, quantified and/or mapped once a good understanding is gained of current and projected differences between supply and demand, and how this affects users. This is exactly the aim of most water accounting procedures.

Information is a critical element for mediating and conferring power within societal relations. Without correct information society has no basis on which to challenge factual errors or biased positions. Effective planning and negotiations are nigh impossible if stakeholders are working with their own, differing, information bases. Yet, such a situation is very common. For example, at national level, government departments in charge of different sectors rarely share a common information base. At local level, incorrect or incomplete understanding of the volumes and distribution of water use often leads to underestimation of pressure on the resource and misconception about decreasing water availability. Similarly, local-level water users may have a very different perception of their service levels as compared with organizations responsible for these services. The key output of water accounting is, therefore, a common information base that is acceptable to all the primary stakeholders involved in a planning or other decision-making process.

5.2 MAIN CHALLENGES ADDRESSED BY WATER ACCOUNTING

For those interested in the long-term management of water resources, the dynamic nature of physical processes and societal responses, as well as the great variability in space, pose a big challenge. Uncertainty is generally high, with availability of resources, the condition of infrastructure and user demands changing continuously. Local populations are often responding to driving forces that are far beyond the control of government departments or water management professionals.

The increasing use of groundwater for irrigation in recent decades also poses problems for water accounting, since both the stock of this resource and the rate at which it is depleted and replenished are difficult to measure with any accuracy. This is particularly the case for conjunctive use of water, where recharge is a function of irrigation; less so for non-recharging 'fossil' aquifer systems.

As a result, water management plans need to be both problem-focused (i.e. matched to the specific challenges in a specified domain) and dynamic in nature. Similarly, the degree of detail in water accounting procedures needs to be adjusted as both conditions and challenges change.

Adaptive management is based on an acceptance that in complex situations there can never be sufficient information to come to an 'optimum' decision. It therefore puts the emphasis on flexible planning, backed by strong monitoring and information management systems that allow constant adaptation and upgrading of plans and activities. Such a level of responsiveness is only possible if information bases are maintained current, based on monitoring and evaluation systems that continually provide decision-makers with reliable information on which to base decisions. This principle is scale independent: it applies not only to decision-makers at policy or management levels, but is also highly relevant to end users, in particular farmers.

5.3 TYPES OF WATER ACCOUNTING

Water accounting involves taking a comprehensive view of the water resources and supply systems, and relating these to society's demand and actual use. Explicit consideration should also be given to the specific water requirements of aquatic ecosystems and the potential impact of drivers that are outside the control of water governance systems (e.g. climate change or energy prices).

The nature and design of a water accounting procedure should be based on the context and need that is to be addressed. Experience has shown that water accounting often needs to be carried out in several steps of increasing complexity, with a first 'back of an envelope' assessment guiding subsequent cycles of more detailed and focused information collection as needs arise. Choosing the required type of water accounting depends on the *geographical scale* required, as well as the *time horizon* relevant to the issues concerned. For some purposes a national water balance is called for; elsewhere it is more appropriate to focus on the river basin (as in the requirement of the EU's Water Framework Directive for River Basin Management Plans). A distinction also needs to be drawn between one-off water accounting procedures that are designed to support a project or a programme, and water accounting that is part of a long-term adaptive management programme aimed at sustaining acceptable levels of water management. Examples of water accounting approaches are discussed below.

Macro-economic water accounting: the System of Environmental and Economic Accounting for Water

The System of Environmental and Economic Accounting for Water (SEEAW)[5] is a comprehensive water accounting system that has been developed with the objective of standardizing concepts and methods in water accounting (UNSD, 2012). SEEAW provides a conceptual framework for organizing economic and hydrological information, permitting a consistent analysis of the contribution of water to the economy and the impact of the economy on water resources. SEEAW is a refinement of the earlier and broader programme of the United Nations to develop environmental ('green') national accounts attempting to measure the economic impact of environmental flows, and additions or depletions to stocks (UN, 2003). The ambition of these accounts would be twofold: on the one hand to give policy-makers information about the impact of current economic policies and growth patterns on the environment (and whether they are sustainable); and, on the other hand, to gauge the impact on the economy of policies taken for environmental reasons. One of the underlying aims is to assess how much of economic 'growth' as it is conventionally measured is actually capital consumption due to resource depletion (World Bank, 2006).

SEEAW aims to reconcile flexibility with the provision of a standardized approach. However, it requires large amounts of information, much of which is not readily available or collected routinely by government departments or agencies. Setting up SEEAW to support practical decision-making, which will be time-consuming and expensive in both start-up and running costs, may be warranted in some situations, but more adaptable and cost-effective approaches will be appropriate in other circumstances.

The approach is well suited to the analysis of the interaction between the economy and the environment when depletion of stock of a given resource must be assessed against economic gains. In the case of water, however, fluxes are more important than stocks, as the resource renews itself on a yearly basis through the hydrological cycle. In contrast to mineral resources or biodiversity, irreversible depletion of stocks remains marginal in the global water cycle [6], and this may not be reflected sufficiently in the SEEAW methodology.

Filling the gap between supply and demand: the water cost curve approach

The concept of the water cost curve has been developed to assist countries facing future water scarcity in assessing future 'water gaps' and analysing possible responses (2030 Water Resources Group, 2009). This tool systematically assembles all the feasible options for either saving or providing water and arrays them, weighted by the water volumes involved, according to their unit cost. Combined in a single graph, the options describe a rising supply curve, a familiar concept in elementary economics. The water supply curve was applied to India, China, South Africa and the Sao Paulo region of Brazil to help prioritize measures to mitigate their respective looming water scarcities.

5 See: http://unstats.un.org/unsd/envaccounting/SEEAWDraftManual.pdf

6 The most relevant application of the economic-environmental accounting approach for water would be to assess the implications of depletion of fossil groundwater aquifers, or encroachment on environmental flows.

One of the attractions of the water cost curve is that it enables a direct comparison of supply-enhancing and demand-management options. Demand management measures are often more difficult and less politically rewarding than new infrastructure, while the re-allocation of water is politically risky. As explained in Section 3, the public funding of supply enhancement is often the preferred option for decision-makers, even where it is second best in economic and hydrological terms. It is not uncommon for supply-side development options to be selected even where all available resources have been developed and allocated. This inevitably produces conflict between users and further environmental degradation or, in the best cases, to restrictions imposed on all users.

While the approach has the merit of comparing options in economic terms, it has some important drawbacks. Many of the proposed measures are interdependent, and, for technical and institutional reasons, a simple sequence of independent options based on the logic of unit cost alone is often not feasible. Furthermore, water savings obtained from different options can rarely be summed, and the gains from a set of options will often be lower than the sum of the gains of these options taken separately. More important is the potential impact of water saving options on downstream availability of water for other uses.

The authors of the water cost curve explicitly state that the methodology focuses exclusively on the technical planning and investment economics aspects of water management, leaving aside issues related to the political economy, institutions, organization and governance. Yet these are often the places where conditions are set for successful application of technical options and investments.

Also, the measures need to be implemented by different parties: private users, companies and public authorities, each with their own constraints and incentives. Such factors mean that the water cost curve cannot be applied uncritically as a decision tool for addressing water scarcity. A series of challenges to adoption have been identified (2030 Water Resources Group, 2009) of financial, political, structural, organizational and social natures, which may represent a barrier to adoption of proposed technical options. They represent the hidden costs of these options, with potentially significant impact on their ranking on the cost curve.

Nevertheless, the water cost curve methodology has several advantages. It is a useful criterion to use, alongside others, in negotiating plans to address water scarcity. In systematically listing all possible options in a transparent way and comparing them in terms of their cost-effectiveness, it provides a useful platform for negotiating water scarcity coping strategies and programmes. In this report, we propose to apply the cost curve through the food production and supply equation rather than through the water gap itself. Such an approach helps address many of the above problems while keeping the main elements of the national level water balance.

Participatory groundwater monitoring

As farmers experience a growing scarcity of irrigation water they have in some regions taken steps to monitor their water resources as a first step towards collective management. In Andhra Pradesh, where farmers rely on groundwater from a set of relatively thin and discontinuous aquifers, depletion during drought years triggered concern over long-term access to groundwater. A state-level programme of participatory groundwater monitoring was implemented to manage the production risk from year to year (Box 1).

Trade in water rights: accounting for Australia's water

Water availability is a major issue for Australia, particularly as rainfall varies a lot seasonally, yearly and across the continent. As the competition for water increases, so the trade in water rights between sectors and between regions increases. In Australia, systems are in place to account for the volume and value of water being traded, but the ad hoc and inconsistent development of those systems may lead to divergent understandings. Therefore, so-called General Purpose Water Accounting Reports (GPWARs) are prepared to assist users in making and evaluating well

BOX 1

Collective participatory management of groundwater in Andhra Pradesh

The Andhra Pradesh Farmer Managed Groundwater Systems (APFAMGS) project was supported by the Government of the Netherlands and FAO between 2006 and 2010 in response to widespread drought and out-migration across the State. The project aimed to improve groundwater management by empowering farmers in monitoring and managing groundwater resources. Groundwater management committees in each aquifer or hydrological unit came together to estimate the total groundwater resource available and work out the appropriate cropping systems to match. The committees then disseminated the information to the entire farming community and acted as pressure groups encouraging appropriate water saving and harvesting projects, promoting low-investment organic agriculture and helping formulate rules that would ensure inter-annual sustainability of limited groundwater resources.

Some 6500 farmers in 643 communities have been trained to collect data fundamental for the understanding the local aquifers. At each of the 191 rain gauge stations a farmer records daily rainfall. At more than 2000 observation wells, farmers carry out daily and fortnightly measurements of groundwater levels. In all, more than 4500 farmers, men and women, are voluntarily collecting data in some 630 communities. The data are maintained in registers kept at the groundwater management committee offices and are also entered on village display boards. At the aquifer level, hydrological unit members are trained to use these data for estimation of groundwater recharge into the aquifer following the end of the summer (southwest) monsoonal rains. Owing to significant variations in local hydrogeology, the calculations are specific for each aquifer and follow the standard methodology developed and used by India's Central Ground Water Board. In terms of cumulative water abstractions, 42 percent of the hydrological units have consistently reduced the rabi (dry season) drought over the three years of project operation, while 51 percent have reduced the drought intermittently, and only 7 percent have witnessed an increase in groundwater drought during this period. This impact is unprecedented, in terms of reductions actually being realized in groundwater withdrawals, and in terms of the geographical extent of this impact, covering dozens of aquifers and hundreds of communities, with an approximate outreach of 1 million farmers. While these results are being assessed through an *ex post* evaluation, APFAMGS can be cited as an example of large-scale success in groundwater management by communities.

Project website: www.fao.org/nr/water/apfarms/index.htm

informed decisions about the allocation of resources. GPWARs are prepared by water managers and address the general information needs of water users, water market investors, traders and brokers, environmental organizations, auditors, financiers, local governments, researchers, planners and policy formulators. By providing access to reliable and assured information about how water resources are managed, shared and used, including information on water rights, claims to water and obligations against that water, GPWARs are designed to enhance user confidence in their water-related investment decisions (Water Accounting Standards Board, 2009).

Water accounting based on remote sensing

Using remote sensing for water accounting has the advantage that it is applicable without the need for extensive field monitoring and data collection. The approach developed by Bastiaanssen (2009) focuses on the water consumption of four different types of land use: protected areas, pastures, rainfed and irrigated agriculture. The approach makes a distinction between beneficial and non-beneficial parts of evaporation, transpiration and interception, expressed in productivity per unit of land and productivity per unit of water consumed.

Since the approach is based on remotely sensed information, it has the advantage that a study can be implemented in a short time and that the source of information is neutral and does not depend on field data that might or might not have been collected already. Since it focuses on water consumption of different types of land use, it is less amenable to taking into consideration water use sectors with large return flows that are not area bound, such as industry and the domestic sector.

Water accounting by product: the water footprint concept

Water accounting by product consists in assessing the volume of water needed to produce one unit of a given product (or service). It is therefore an important element in assessing demand for water. A corollary, the *water footprint* concept aims to measure the impact of specific products, or firms, on water resources. This technique has been used to draw policy conclusions for water-scarce regions about the desirability of locating production in certain areas rather than others; local production versus import; the benefits of specializing in some products rather than others; etc. Footprinting arose out of the concept of virtual water – the amount of water embodied in traded goods and services.

A growing number of studies (e.g. Chapagain and Hoekstra, 2004; WWF/SAB Miller, 2009) purport to measure the water footprint of different countries and specific products. Most studies demonstrate, for instance, the high water footprint of meat, which implies growing pressure on the water resources of meat producing and exporting countries, as growing affluence leads populations to shift to a diet containing more meat and dairy products. Other studies have considered the water footprints of cereals, cotton, beer and other products. Footprinting has the virtue of confronting producers and consumers with the potential impact of their behaviour on water, hence identifying their water risks.

While it sheds interesting light on the water-related impact of consumption patterns, the concept of the water footprint still suffers from a set of methodological difficulties, including the differentiation of consumptive and non-consumptive use; the source of water (rainfall or freshwater from rivers and aquifers); and the problems of tracing, and adequately accounting for, the upstream and downstream impacts of production (purchases from suppliers and other inputs, transport and use by consumers outside the boundaries of the farm, mine or factory).

An important application of the technique of water accounting is that it allows measurement of the volume of water use by specific amounts of product (water productivity). In agriculture, actual crop yields (kg/ha) depend on water availability, but also of a series of factors, some related to soil and climate, and others related to management and agricultural practices, and a wide range of yields can be obtained for a given volume of water used. Low yields therefore translate into low water productivity, while good agricultural practices associated with sufficient water supply can easily multiply water productivity by a factor of 2 to 4.

Water accounting for firms

Apart from water footprinting, there are several other tools available to assess the exposure of specific firms to water scarcity and other water risks, and at the same time to estimate the likely impact of their production on local water supply–demand balances (hence the firm's *reputational risk*).

A Life Cycle Assessment (LCA) measures "the environmental sustainability of products and services through all components of the value chain." LCA has been incorporated into the legislation of a number of countries and international guidelines, such as in ISO standard setting. It measures the resource use and pollution that can be ascribed to a particular product at all stages of its production and lifetime of use (including eventual disposal). Studies of foodstuffs and other agricultural products have been particularly numerous. Although water is only one of the environmental impacts considered in most LCA studies, there is no reason why water-specific LCA should not be carried out.

Some of the methodological challenges facing LCA are: the consumptive vs non-consumptive use distinction, identifying the geographical location and nature of source of the water, and what is renewable and what non-renewable. Tracing the impact of the product throughout its useful life, and assessing the impact of its disposal as waste, is also problematic.

The *Global Water Tool* of the World Business Council for Sustainable Development is a tool to enable companies to better understand the impact of their operations on the local basin and their potential exposure to the risk of water scarcity or the risk to their reputations amongst local communities, as well as among their own shareholders and consumers. The Tool combines available country and basin data (including maps and Google Earth images) with indicators calculated for specific sites and regions.

The *Water Sustainability Tool* of the Global Environmental Management Initiative (GEMI) is another online tool to help companies and other organizations build a water strategy and understand issues of water sustainability in relation to their operations.

5.4 FROM WATER ACCOUNTING TO WATER AUDIT

Together with a clear understanding of the hydrological cycle – including supply, demand, recycling, and quality of water – water scarcity coping strategies also require a sound understanding of the institutional, social, environmental and financial dimensions of water management within a basin. While the term water accounting refers to a systematic study of the current status and future trends in both water supply and demand in a given spatial domain, the water audit places this account into the broader framework of institutions, finance and the overall political economy (Table 3).

There are a number of factors that cause water scarcity, which interact, but which may have independent origins. A systematic review of resources, infrastructure, demand and access, combined with understanding of governance, finance and the overall political context, is therefore needed to perform a diagnosis of the problems and elaborate response options. This is valid at the scale of a village irrigation system, where the problem can be either infrastructural (e.g. a pump breakdown), societal (e.g. social exclusion from using certain water points) or resource related (e.g. falling groundwater levels), as well as at other scales: a local catchment, a district, a country or a large, transboundary river basin.

TABLE 3
From water accounting to water audit

Mapping water supply and demand	Mapping organization and management	Mapping socio-economics and finances	Mapping governance
Surface water: volumes, distribution	Infrastructure operations	Rural/urban population: incomes, health, education levels, water use	Water policies, agricultured policies, food security policies, environmental policies
Groundwater: aquifer characteristics	Farming practices, productivity, productivity gaps	Typologies of water users in agriculture	Institutions: mandate, interactions, effectiveness, level (national, river basin, local)
Infrastructure: regulation capacity	Technical efficiency in water use, conveyance losses	Gender and minorities: rights, access to water, use	Laws and regulations, enforcement
Demand: agriculture, cities, industries, environment		Water charges, incentives, development programmes (catchment management, etc.)	
Water quality, water treatment			
Return flow, recycling			

6. Policy and management response options

The first stages of water management typically focus on supply enhancement, consisting of the development of technology and infrastructure in response to increasing demand. The paradigm of supply enhancement has tended to view demand simply in terms of needs to be satisfied. In the new era, where water-scarce regions are embarking on demand management programmes, it is becoming evident that demand, which depends on human needs, behaviour and values, and the way societies operate and organize themselves, represents a far more complex challenge than supply (Brooks, Rached and Saade, 1997).

The different roles, attitudes and strategies of the various stakeholders involved in water policy and management need to be clearly understood. Table 4 shows the objectives of major groups of decision-makers at different levels, and the strategies at their disposal to address water scarcity. Within a common purpose to cope with growing water scarcity, the objectives of specific groups may be misaligned or even conflicting. To avoid this danger, the policies of different sectors need to be harmonized (especially between agriculture, water resources and the environment) and the private incentives influencing farmers should be aligned with the overriding public purpose of optimizing water use. The same applies to the different parties at all levels of water management.

This section assesses options available to decision-makers for developing strategies for coping with water scarcity. It distinguishes between options within the water domain, those that are of direct concern to agriculture and those related to national food security strategies. This distinction recognizes that institutions dealing with water resources management and those dealing with agriculture and food supply have different objectives and sector-specific mandates. Table 5 presents a summary of possible options, which are further discussed in this section.

6.1 OPTIONS WITHIN THE WATER DOMAIN (ALL SECTORS)

This section discusses response options on both the supply and the demand sides. For managing supply, the options considered here are increased storage, groundwater development, recycling and re-use, pollution control, and desalination. In demand management, the options are divided into re-allocation and increased efficiency of use.

Not all response measures fit easily into these two categories. For instance, improvements to the distribution of water could be regarded as either supply-side or demand-management measures, depending on where they fall in the continuum from source to user. Likewise, the repurchase and restriction of historical water rights, which is happening in Australia, and which occurred in South Africa through the 1998 National Water Act, could be regarded as a supply-side (restriction) measure, or as a measure for promoting the economic efficiency of water use, or as re-allocation (to the environment).

TABLE 4
Strategies and policies for coping with water scarcity according to categories of decision-makers

Level	Supply side	Demand side
WHAT: OBJECTIVE		
National water authority	Providing safe and sufficient water to all sectors of the economy while maintaining the integrity of the resource base	Ensuring efficient and sustainable use of freshwater
National authority for agriculture and irrigation	Securing sufficient water supply to satisfy the needs of the agriculture sector	Ensuring highest productivity of water used in agriculture
River basin or aquifer authority	Ensuring that available supply of water is provided to all users in a transparent, reliable and effective way	Ensuring efficient and sustainable use of freshwater by all users at river basin or aquifer level, avoiding conflicts and ensuring environmental protection
Irrigation scheme manager; Water User Association	Ensuring that a sufficient supply of water is provided to all users in a reliable, timely and effective manner	Ensuring that available water is used in the most productive way
Farmers	Securing supply of water for all farm operations	Using available water most productively and profitably
HOW: STRATEGIES & POLICIES		
National water authority	Construction of multi-purpose dams, desalination plants, inter-basin transfer, Pollution control, negotiation of transboundary allocations; establishment and enforcement of environmental flows	Adaption of water laws; development of water institutions; tighter enforcement; promotion of water markets; trade mechanisms; water charges or quota mechanisms; administration of water rights; water allocation and water quality standards; public awareness campaigns; buy-back for environmental purposes
National agriculture and irrigation authorities	Construction of irrigation dams; negotiation of water allocation to agriculture	Incentives for irrigation modernization; adoption of service-oriented management of irrigation; adaptation of irrigation infrastructure for increased flexibility and reliability of water supply; review of agricultural water tariff policy
River basin or aquifer authority	Construction of large dams, dam operation rules, aquifer recharge, well drilling (groundwater development)	Optimization of dam management; management of water allocation mechanisms; administration of groundwater use; pollution control
Irrigation scheme manager; Water User Associations	Negotiation of water allocation, recycling of drainage water; collective land improvements, on-scheme storage development and management	Reducing losses in distribution; incentives for increased economic efficiency of field-level water use (subsidies, volumetric pricing, water markets)
Farmers	Individual well drilling; re-use of drainage water; on-farm water conservation investments; on-farm water storage; trading water; scavenging water; collective action	On-farm efficiency improvement (pressurized irrigation), deficit irrigation, adaptation of crops and crop varieties to water supply conditions

TABLE 5
Summary of options to cope with water scarcity

		Measure		All sectors	Agriculture
Supply side options	Within the water domain	Reducing inter-annual variability of river flow		**Increased storage (multi-purpose dams)**	**On-farm water conservation**
		Enhancing groundwater supply capacity		**Groundwater development**, management and artificial recharge	Aquifer recharge enhancement in irrigation
		Water recycling and re-use		Closed loop re-use and recycling	**Re-use of urban wastewater for crop production**
		Pollution control		Point source pollution control (industry, cities)	**Integrated plant production and protection, control of pollution from agriculture (including payment for environmental services)**
		Importing water		**Inter-basin transfer, desalination**	
Demand-side options	Within the water domain	Reducing water losses		Improved monitoring, leakage control, closing circuits (industry)	**Pressurized conveyance and application of water (drip), improved irrigation scheduling and moisture control, canal lining**
		Increasing water productivity	through better water control	Better water management mechanisms, enhanced predictability of supply, early warning	**Improved water delivery service in irrigation (increased reliability and flexibility of water delivery through modernization of infrastructure and management), precision irrigation, deficit irrigation, drainage in irrigation**
			through improved production process	Dry cooling (power)	**Yield gap reduction through improved agricultural practices (fertility management, pest control), improved genetic material**
		Water re-allocation		**Intersectoral transfer** (through water markets or other water allocation mechanisms) **Intrasectoral transfer** (including restraining demand)	**Shift to higher value crops in irrigation and/or limiting evapotranspiration by reducing areas under irrigation**
	Outside the water domain	Reducing losses in the value chain		Waste control, improved processing and distribution	Reduction of post-harvest losses: storage, processing, distribution, final consumption
		Reducing demand for irrigated products and services		Import of manufactured products	**Reduced yield gap in rainfed production** (improved agricultural practices; fertility management; pest control; soil moisture management: mulching, weeding; drainage, improved genetic material, seasonal forecast and crop insurance schemes).
					Import of food and other agricultural products **(virtual water trade)**
		Reducing water use per capita		Changes in consumption habits	**Changes in food consumption patterns** - less water intensive diets

Options in bold are discussed in further details in this report

Managing supply

In order to have secure access to water, limit the damages of floods and overcome droughts, people have always tried to control and store seasonal and irregular water flows. Managing the supply can be done by increasing access to conventional water resources, including dam storage, groundwater withdrawals or harvesting rainwater. It can also be done through re-using wastewater and drainage water or through developing 'non-conventional' sources of water, including desalination of brackish or salt water and the use of fossil groundwater.

Increased water storage

The second part of the twentieth century saw a rapid increase in the development of surface water reservoirs, leading to remarkable achievements in water mobilization. Large multi-purpose dams have met the growing needs for water for agriculture, energy generation and cities, and helped protect populations from flood hazards. While the potential for further dam development still exists in some regions, most of the suitable dam sites are already in use, and the development of new dams is becoming increasingly costly.

Since the late 1990s, controversy over large dams has restricted their further development in many countries, due to concerns about underestimated environmental and socio-economic impacts. Future large dams will increasingly need to be justified in economic, social and environmental terms.

At household and community levels, small decentralized water harvesting and storage systems have increased the availability of water and boosted agricultural production. These small-scale measures promote local economic development and increase the climate resilience of local communities. Such decentralized water measures, however small, do still have an impact on the catchment's water balance (Batchelor, Rama Mohan Rao and Monahar Rao, 2003). Large programmes of small-scale water harvesting, like the local basin management programmes developed in Andhra Pradesh and other parts of India (Rao *et al.*, 2003) have had substantial impacts on the basin's overall hydrology and the availability of water downstream.

The concept of *green infrastructure* is becoming more prominent in water supply management. This approach seeks to safeguard critical functions of the natural environment through regulation and planning measures. In this context, wetlands and forests play a crucial role in regulating the flow of water in support of downstream users.

Groundwater development

Intensive groundwater exploitation has grown exponentially in scale and intensity over recent decades. Global withdrawal of groundwater is estimated to have grown from a base level of 100–150 km^3 in 1950 to 950–1 000 km^3 in 2000 (Shah, Burke and Villholth, 2007), with the bulk of this growth being concentrated in agriculture. Latest available estimates based on comprehensive national and sub-national statistical data indicate that 40 percent of actually irrigated area in the world can be attributed to groundwater sources (Siebert *et al.*, 2010), with an estimated annual abstraction level for agriculture of 454 km^3.

Irrigated agriculture is the principal user of the major sedimentary aquifers of the Middle East, North Africa, North America and the Asian alluvial plains. The groundwater boom has been driven by the demand for irrigated production and facilitated by government subsidies and the ready availability of affordable pumps and drilling technologies. The capacity of groundwater to provide flexible, on-demand water for irrigation is a major advantage to farmers. In India, crop yields from farms irrigated by groundwater were found to be 1.2 to 3 times greater than farms irrigated with surface water (Shah *et al.*, 2000).

While the growing use of groundwater has improved the livelihoods of millions of rural people (Moench, 2002), it has also caused depletion of aquifers, pollution of groundwater and the intrusion of sea water. The problem with groundwater is that, as an open access resource, there are strong incentives to deplete it. In cases like India, farmers have been provided with very cheap electricity, thus further encouraging depletion of the resource. There is, however, an important difference between shallow alluvial aquifers that are replenished during each rainy season, and deep aquifers with slower rates of recharge.

Existing trends cannot be sustained without much more effective management of groundwater (Shah, Burke and Villholth, 2007). However, since groundwater development is mostly undertaken by individuals, it is difficult to regulate and monitor, and the legal basis for this is often absent (FAO, 2003). When legislation exists it faces serious enforcement challenges. This hinders measures for the conservation and efficient use of groundwater. A very basic problem is that the notion of 'sustainable yield' is elusive, hard to measure, and difficult to apply in practice (e.g. COMMAN, 2005). This concept has also fostered the false idea that groundwater use does not affect other natural environmental functions. Despite these problems, progress has been made in designing successful community-based groundwater management processes (APFAMGS, 2009).

Managed aquifer recharge is a potentially important option, but depends on a greatly improved understanding of groundwater storage and recharge rates. In some hydrogeological settings it is difficult to improve the efficiency of natural recharge processes, while in others the economically feasible proportion of recharge enhancement over natural recharge is very limited, although the techniques can help solve local problems and improve groundwater quality. The highest management priority, though, will always be to protect the main recharge zones, and in this context the encouragement of aquifer recharge in large irrigation schemes has been discussed as an alternative to improved water service to users (Shah, 2009). In any case, groundwater recharge must be designed within a clear water budgeting framework to ensure the effectiveness of options selected.

Water recycling and re-use

Investments in water supply, sanitation and water management tend to be planned, designed and managed separately, and with different time horizons. The creation of environmentally sound systems that take into account the whole water cycle for various users calls for a coherent approach to overcome sectoral boundaries and the rural-urban divide. Managing wastewater is essential for several reasons. First, wastewater is often discharged in places where it cannot be re-used, or directly to the sea, thus losing an opportunity for beneficial use. Second, wastewater is often rich in plant nutrients, and these and the residual water can both be put into beneficial use through irrigation. Re-use for agriculture, following primary or second stage treatment with low-cost ecological technologies, can be a cost-effective and win-win solution in these circumstances.

Pollution control

Pollution reduces water available for use and increases the cost of water treatment. The costs of not addressing pollution are high and some impacts may be irreversible (contamination of groundwater drinking water, ecosystem losses). Polluted water has a high cost to human health: one-tenth of the global burden of disease can be attributed to water (WHO, 2004). Other pollution costs include clean-up, additional treatment and damage to fisheries, ecosystems and recreation. Most countries have introduced legislation to protect their water resources, but implementation often lags behind because responsibilities are dispersed across multiple institutions, political will to antagonize industrial interests is lacking, and the costs of control and monitoring are high.

There are examples (mostly in developed countries) where the 'polluter pays' principle has stimulated changes in attitudes towards pollution and led to increased recycling, with development of clean processes for industry or management of effluents in an 'end of the pipe' approach that collects, controls, treats and monitors performance. However, investments for such approaches are often lacking at all levels, from household sanitation and industrial processes to city waste treatment plants.

With increased intensive agriculture, pollution from both point and non-point sources, will worsen. Technologies exist to limit agricultural water pollution, in particular through integrated pest and plant nutrition management. Experience from high-income countries shows that a combination of incentives, including more stringent regulation, enforcement and well targeted subsidies, can help reduce water pollution. In some cases, the payment for environmental services approach has led to a noticeable reduction in agricultural pollution and savings in water treatment costs downstream of agricultural land.

Inter-basin transfer and desalination

The transfer of water from a water rich to a water-scarce basin has been practice in many regions and offers an opportunity to address local imbalance between supply and demand. With increased concern about the value of water and the necessity to secure water flows for the future, negotiations between regions on inter-basin transfer are becoming increasingly complex and hard to conclude.

Desalination of seawater and brackish water is increasingly affordable due to progress in membrane technology. This process is used mostly for drinking water and industrial supplies in countries such as Malta, Cyprus, Israel and the Gulf States, where water withdrawal has reached the limits of the total renewable water resources. Desalination is not widely used for agricultural water. High energy costs and brine disposal are considerations, but its use for high-value crops is practiced where there is physical water scarcity and market demand and agro-climatic comparative advantage in certain export crops coincide, particularly in the Mediterranean. In Morocco plans exist to build a desalination plant for the irrigation of cash crops. Desalination accounted for only 0.4 percent of total water use in 2004 (nearly 14 km^3/yr), but production is expected to double by 2025. Indirectly, desalination for urban water supply can free water for other uses, including agriculture (FAO, 2006b).

Managing demand

The general aim of demand management is to ensure that a given supply of water is distributed to accord more closely with its 'optimal' use pattern. In economic terms, this will be achieved when the marginal unit of water for each user has the same value (Winpenny, 1994). The aim of equalizing marginal values of water in all uses[7] is a theoretical ideal, but where water becomes scarce, and its cost of supply is increasing, it is important for policy makers to encourage society as a whole to make the most

7 The so-called Pareto Optimum, in which it is impossible to raise general welfare by re-allocating the good any further.

'productive' use of the water available, however this is conceived. This can be pursued by giving incentives to individual users to make more 'efficient' use of water and by encouraging a shift of water from less to more beneficial[8] purposes. These two approaches are discussed below.

Making more 'efficient' use of water

The aims of 'more efficient' and 'more productive' use of water are two sides of the same coin. *Efficiency* emphasizes the 'process' and is a dimensionless ratio between outputs and inputs, while *productivity* puts the emphasis on the 'output' and in the case of water productivity is measured in terms of units per volume of water. Under this type of demand management, users are encouraged to reduce water losses and waste, cut out low value water applications, and maximize the value obtained from their remaining water. 'Value' in this context includes non-monetary benefits as well as values estimated by 'willingness to pay' and other economic valuation techniques.

The term 'water use efficiency' is sometimes used in a narrow sense as the ratio between beneficial use and water withdrawals. This applies to the notion of 'water supply efficiency' or 'irrigation efficiency', where the difference is analysed between water withdrawn and the physical losses resulting from leakage from pipes and canals and wastage through excessive or inappropriate application for the crop or productive process. Urban distribution networks and irrigation schemes lose large amounts of water through leakage and percolation. Among the 23 countries of the Mediterranean, an estimated 25 percent of water is lost in urban networks and 20 percent from irrigation canals, while global estimates of irrigation efficiency are around 40 percent. Appreciating the real scope for water savings by reducing these losses is an important issue in water demand management, but can only be identified through water accounting procedures.

However, two factors limit the scope for, and impact of, reduction in losses. First, only part of the water lost to beneficial use can effectively be recovered at a reasonable cost. The leakage rate from old urban water networks is often used as a proxy for network efficiency, yet replacing the pipes and fittings can be expensive and highly disruptive[9]. Second, part of the water 'lost' between the source and final user finds its way back into the hydrological system, either through percolation into the aquifers or by return flow into the river systems (Perry, 2007). The share of water lost through *non-beneficial consumption*, either through evaporation or drainage into low quality water bodies or to the sea, varies extensively according to local conditions. There is also a difference between losses in urban and industrial locations, and those in farming areas, and between upstream and downstream situations. A clear understanding of the scope for real gain in reduction of losses is therefore necessary to avoid designing costly demand management options that will have little effect on the availability of water for the hydrological unit considered as a whole. In this situation, water 'losses' may from another viewpoint be 'unintended uses' and it is important to track what 'lost' water is actually used for, if anything.

This being said, targeting the reduction of losses in distribution systems is still justifiable in many cases. Excessive levels of losses and leakages reflect failures of infrastructure or its management, and cause financial costs (for producing, pumping and transporting

8 The term beneficial is more inclusive and less pejorative than "productive".

9 In England and Wales the water regulator OFWAT uses the concept of the "economic level of leakage", specific to each company, at which the value of the water to be saved by further leakage control equals the cost per unit of doing so.

water), as well as degradation of the distribution system, increased environmental and health risks, and lost opportunities for beneficial use of water. In irrigation, for instance, losses in distribution may reduce the water available to the 'tail ender' irrigators.

Re-allocation of water

The shift of water from less to more beneficial uses can be achieved through a combination of pricing, other market mechanisms and administrative devices. Once essential human and environmental water needs have been met, applying a 'shadow price' to the remainder of this scarce resource would encourage its application to the most productive (or beneficial) purposes. In a market regime, water would flow from lower to higher value use[10].

When considering only commodity production, agriculture tends to have a much lower added value per unit of water than other sectors. On this criterion, re-allocation would normally favour other sectors such as cities, industries, tourism or recreation. However, the picture is complicated by the multiple roles that agriculture plays in society: social, cultural, religious and environmental, as well as production. In many developing countries agriculture provides a living for a large proportion of the rural population. Furthermore, the need for governments to secure sufficient supply of food to satisfy the population's basic needs is receiving renewed attention in the light of current food price volatility. The desire for national food sovereignty therefore introduces another set of considerations. Valuing the multiple benefits of water in agriculture has to take account of all these societal choices and values.

In a few regions (Chile, parts of Australia and some western states of the United States of America) the conditions have been created for regular water trading. Water markets are commonly used by farmers wanting supplementary water for valuable crops during drought conditions or by cities to meet their growing water needs. The actual prices set in these markets signal the marginal values of water in these different uses, which are usually much higher than average values. However, the typical markets are very localized and very imperfect in the theoretical economic sense. As one recent study noted, "price observations from one context may have little relevance in another" (Aylward *et al.*, 2010).

In a large majority of countries, water markets, based on established, secure and tradable water rights, are not a feasible option. In these countries, intersectoral allocation or re-allocation of water can be achieved through administrative measures. Whether re-allocation is made through market or administrative devices, society has to set limits on transfers to protect third parties, the environment and the wider social interest. Subject to these conditions, competition for water can be conducive to improved allocation efficiencies. Using trade mechanisms, some organizations even 'compete' on behalf of the environment by purchasing the rights to a certain volume of water in a river or lake, which they then leave in the water body as an 'environmental flow'. In Australia, a Commonwealth Environmental Water Holder has been created to manage water entitlements purchased for the environment by the government's water buyback programme, and 50% of all water saved through the federal government's infrastructure funding programme must be returned to the environment[11].

It is also argued that allowing market or actual water prices to influence allocation would bring supply-side forces to bear on water scarcity, promoting private investment

10 Recall the adage, "water flows uphill towards money".

11 Information from the presentation by Australia at the Expert Consultation.

and technical advances. A number of countries have included more active use of actual water prices amongst their policy responses to water scarcity. In Australia, accurate price signals and effective water markets are seen as an essential part of improving the economic efficiency of water use and encouraging water users to adjust to changing climatic conditions. In South Africa, economic water pricing, in principle, aims to reflect water scarcity, though the level of irrigation charges still has some way to go in this respect to reflect commonly agreed values [12].

The use of market or pricing mechanisms is not applicable in all situations and requires a series of conditions to be applicable. In irrigation, the excessive promotion of simplistic market-based approaches across the board in the 1990s has rarely been successful. In fact, there is much scepticism amongst irrigation professionals about the feasibility and even the desirability of using irrigation charges to encouraging the efficient use of water by farmers. (Molle and Berkoff, 2007). This is a highly complex and controversial issue, and simplistic recipes should be avoided. From a pragmatic point of view, however, it should be pointed out that tariffs serve two purposes – the economic purpose of signalling scarcity, and the financial one of raising revenues for a chronically under-funded sector. In one water-stressed region of Southern Italy, the irrigation water tariff includes, alongside a progressive variable rate per cubic metre, a fixed charge per hectare to cover the cost of maintenance [13]. The next section discusses some of the difficulties inherent in applying water pricing and markets to agriculture as a means of achieving the desired re-allocation of water within this sector.

6.2 OPTIONS WITHIN THE AGRICULTURAL WATER MANAGEMENT DOMAIN

Most of the response options discussed so far are exemplified in agriculture, with features specific to this sector. This section discusses agricultural applications of supply enhancement, loss reduction, crop productivity, re-allocation, and measures for rainfed agriculture.

Supply enhancement

Increasing the availability of water for agriculture can be done at different scales. At the river basin scale, dams for the storage of irrigation water, either for single- or multi-purpose use, represent major, capital-intensive solutions. At a much smaller scale, individual farmers are able to dam rivers and store and harvest water for the benefit of their own operations. At farm level, in rainfed conditions, farmers can practice on-farm water conservation to reduce runoff, and encouraging the infiltration and storage of water in the soil. At this local level, increasing the availability of water is highly decentralized and involves huge numbers of farmers involved in pumping groundwater and developing small-scale water harvesting.

Water recycling and re-use in irrigation

The scale of re-use and re-cycling of drainage water and wastewater is an important part of water accounting. In large-scale contiguous irrigation projects, excess water returns to the system through drainage or infiltration and is re-used within the same system or further downstream. In the Nile Valley, for instance, about 20 percent of the

12 Information from the presentation by South Africaat the Expert Consultation.

13 Information from the presentation by Italy at the Expert Consultation.

water is recycled in this way between the Aswan dam and the sea (Molden, El Kady and Zhu, 1998; Faurès, Svendsen and Turral, 2007). The large-scale paddy systems of South-Eastern Asia follow very similar patterns of re-use. A good estimation of the rate of re-use is essential in gauging the effectiveness of water saving measures: efforts to increase water use efficiency by reducing distribution and on-farm losses may turn out to have marginal net impact when assessed at basin scale.

Although it is of minor global significance, the re-use of urban wastewater in agriculture is of potential importance in a growing number of localities. There are no reliable figures on the extent of municipal wastewater use in agriculture, but direct use of treated and untreated wastewater is significant in certain water-scarce areas such as the Middle East and in the Tula Valley near Mexico City. Efforts are needed to better assess and map current informal wastewater re-use and its potential, particularly in water-scarce areas (FAO, 2010).

Although the major concern about the use of untreated wastewater in agriculture is about the possible hazards to human health, the enforcement of water quality standards is often complicated by ambiguous lines of authority and poor capacity for enforcement. Restricting the crops that can be grown with wastewater is difficult where some crops are in high demand in the local market and are profitable to cultivate. Even where wastewater is not treated to a fully desirable level, the risks to health can still be reduced through awareness raising and the adoption of wastewater irrigation methods that can substantially reduce faecal contamination of crops. Improving hygiene in marketing products has also been shown to be a cost-effective way to protect public health.

Reducing water losses

There has been much controversy and debate about the engineering concept of 'water use efficiency' – the ratio between the amount of water evapotranspired by plants for productive purposes and the amount of water withdrawn or diverted from its source (Keller and Keller, 1995; Keller, Keller and Seckler, 1996; Seckler, 1996; Perry *et al.*, 2009; Frederiksen and Allen, 2011; Gleick, Christian-Smith and Cooley, 2011). It is now widely accepted that, while irrigation losses appear high, with on average about 40 percent of the water supplied to agriculture reaching plant roots on average, a large part of these 'losses' return to the river basin in the form of return flow or aquifer recharge, and can be tapped by other users further downstream or serve important environmental functions. Measures to reduce losses upstream, while maintaining existing levels of withdrawal, will increase the productive efficiency of water use, but, at the same time, may deprive downstream water users who depend on return flow in rivers or groundwater aquifers fed from these returns.

Apparent water 'conservation' may therefore have a perverse impact on the availability of water. Basin development can improve the availability of water for farmers in semi-arid areas, but this often leads to intensification of water usage that reduces its availability in downstream areas (Batchelor, Rama Mohan Rao and Monahar Rao, 2003). Equally, it is possible to walk into a water efficiency trap. Many studies of the application of precision irrigation have shown that water conservation through extensive adoption of highly efficient drip irrigation can increase local consumptive water use and reduce downstream flow (e.g. Ward and Pulido-Velazquez, 2008). These practices may increase the productivity of water but do not necessarily increase the amount of water available for other farmers – indeed, they may reduce this by simply inducing more evapotranspiration, albeit with highly efficient techniques. This is often the case when irrigation of staples is converted into more precise irrigation of horticultural crops with higher crop water requirements and higher cropping intensities. At the scarcity limit, when all sources of water have been exploited and all losses reduced through the application of efficient irrigation, the only option is to reduce the volume of evapotranspiration to conserve and build back groundwater storage or reduce rates of depletion. Attempts have been made to introduce evapotranspiration quotas in the North China Plain (World Bank, 2009).

In the case of paddy rice, excess seepage into the underlying groundwater is already being recovered in many areas through pumping (Frederiksen, 2009). Water that is 'lost' through leakage may eventually be used just as productively as that retained in the irrigation system, even when associated with the extra costs of its recovery through pumping and treatment to obtain water with quality of acceptable standards.

In some cases, over-irrigation may lead to waterlogging and subsequently, especially in (semi-)arid areas, to salinization. To prevent this from happening effective drainage systems can be used and irrigation water can be applied sparingly during the growing season, while salt built-up may need to be flushed away in fallow periods. The water used for the flushing of the soil can be re-used downstream if diluted sufficiently with fresh river water or groundwater.

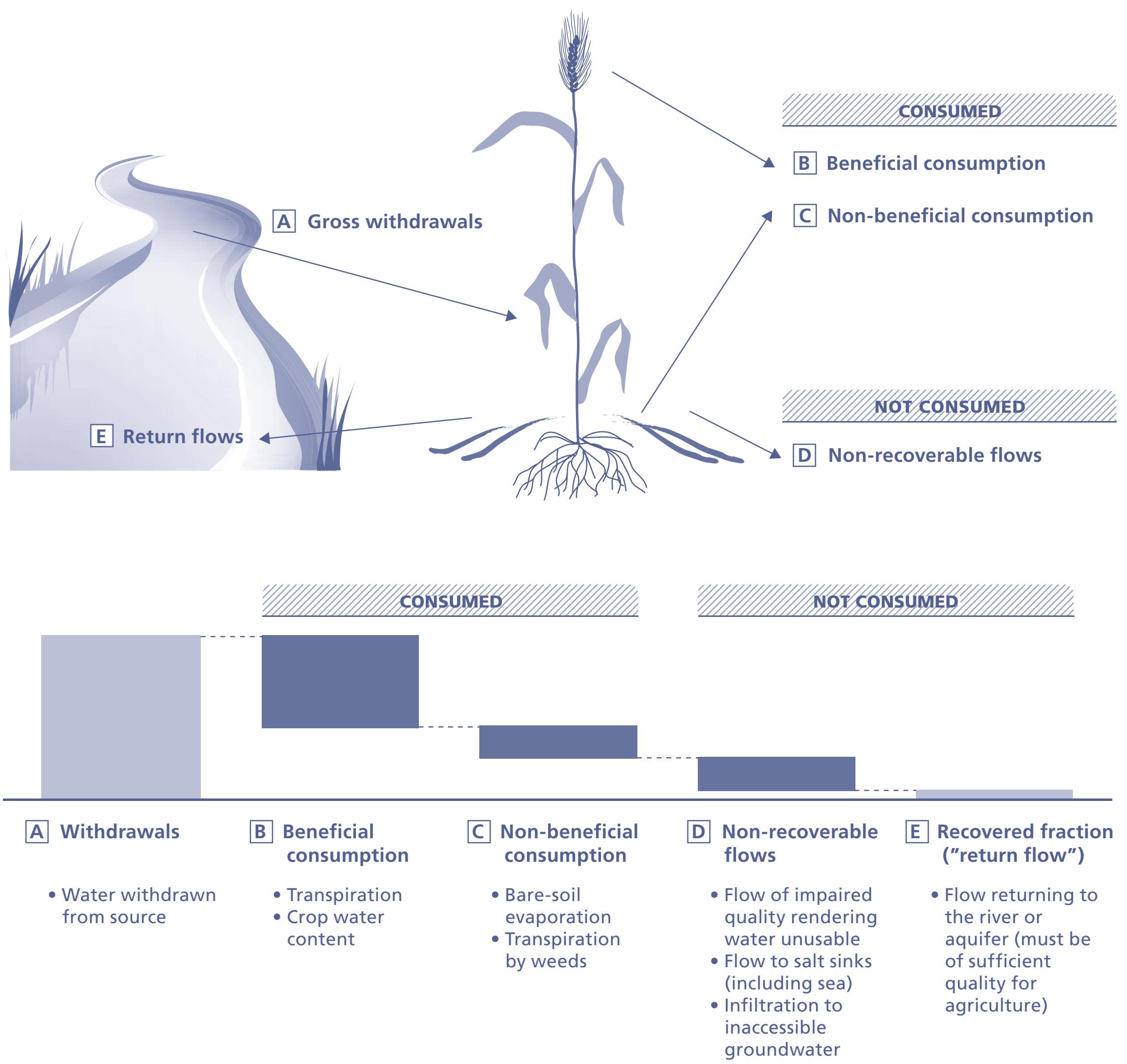
The important conclusion is that measures to reduce losses must be assessed per catchment, and not only at individual farm level. Implications for return flow, its distribution in space and time and recoverable part must be fully understood. Effective interventions to reduce losses in irrigation therefore require a careful evaluation of all the elements of the water balance over a given hydrological system, identifying in particular the share of water supplied that is lost through evaporation, the part that returns to the river or the aquifer and is or can be re-used downstream, the part that is put into beneficial use through evapotranspiration by crops, and the part which is not consumed and is not recoverable (Molden, 1997; Hsiao, Steduto and Fereres, 2007). Only under such conditions can conservation measures be designed in an effective way. The conceptual overview presented in Box 2 offers a way to assess the potential effect of proposed water saving actions in terms of beneficial versus non-beneficial consumption and recoverable versus non-recoverable flow. Such assessments should therefore be conducted systematically.

BOX 2

Components of water withdrawal in irrigation

The figure below presents a conceptual overview of the components of water withdrawal at field level that must be considered when designing demand management programmes (Perry, 2007; Perry *et al.*, 2009; 2030 water resources group, 2010). Water withdrawn from its source can be divided into *consumed* and *non-consumed* fractions, the consumed fraction being the part of water withdrawn which evaporates, either directly from the soil or through plant transpiration. The non-consumed fraction leaves the field, either through deep percolation or flow to downstream land and watercourses. Part of the consumed fraction is put into *beneficial use* through crop transpiration or retained as crop water content, while *non-beneficial consumption* is lost through bare soil evaporation. Of the non-consumed fraction, a *non-recoverable part* will be lost to further use, either flowing to inaccessible groundwater sources, salt sinks or to the sea, or its quality will be affected to the extent that it cannot be used further, while the rest will flow downstream as *return* or *recoverable flow* and is available for further use.

Illustrative overview of the components of water withdrawals in irrigation



Adapted from: 2030 Water Resources Group (2011).

Water conservation options are therefore intrinsically linked to issues of access and rights and allocation among users. As they affect access and distribution of water, conservation measures must therefore be considered within the broader allocation context to ensure that their impacts on users is understood and agreed upon.

The scope exists, however, for the adoption of technologies or management methods that result in reduced losses of water in the distribution and application process, and it would be wrong to automatically discard water conservation measures on the ground that most of the return flow can be used further downstream (Box 3). The share of the non-recoverable fraction and non-beneficial consumption in comparison with return flow and beneficial consumption is very much site specific and varies from one place to another. In addition, water conservation options are usually associated with increased water productivity and other, non-water-related co-benefits, such as reduction in energy use, reduction in labour costs or increased precision and reliability of water delivery (Gleick, Christian-Smith and Cooley, 2011).

BOX 3

Water-saving practices in rice-based canal systems in Asia

In rice-based canal systems in Asia, unbalanced and uncoordinated storage, together with internal distribution problems, has led to 'artificial' water scarcity in many irrigation schemes. A lack of understanding of water balances, of linkages between surface water and groundwater, and of the difference between beneficial and non-beneficial uses of water have usually resulted in poor effectiveness of water saving approaches (AIT, 2009). Nevertheless, water saving practices such as alternate wetting and drying techniques, when integrated with water banking and storage management, can contribute to water saving and increased water productivity. They reduce the non-beneficial consumption of water used in agriculture and therefore represent a net gain in water availability at the level of the river basin. Successful upscaling of such practices requires a good understanding of the constraints preventing farmers from adopting them. Incentives for farmers to adopt water saving measures should focus on irrigation service and infrastructure upgrading, and improved flexibility and reliability of water services. The use of quotas, together with in-scheme water trade, show much more promising results than approaches that promote water charges as a tool for demand management.

The most widely promoted conservation measures include canal lining and conversion from gravity to pressurized irrigation, in particular localized irrigation (micro-irrigation)[14]. Canal lining in large surface irrigation schemes are among the most widely promoted approaches to reduce losses in irrigation, in particular in South Asia. When designed for areas with large, continuous unconfined aquifers, such as the Ganges basin, such interventions may be designed to improve water control and may reduce local leakage, but will not necessarily induce significant water saving across the whole command area. Further, in current conditions, with increasing importance of conjunctive use of surface water and groundwater through the digging of shallow groundwater wells in individual farm plots, gravity irrigation systems with poor conveyance efficiency play an increasingly important role in terms of aquifer recharge. Rehabilitation or modernization planning in such irrigation schemes therefore need to take a much more comprehensive approach to water saving and focus more on the overall productivity of water in a system rather than strict technical efficiency. Canal lining may still be justified in the framework of irrigation modernization plans when it is required to improve water control, or in areas where conveyance losses are high and downstream water recovery is unlikely.

14 Information from the presentation by Italy at the Expert Consultation.

A similar approach needs to be adopted in the case of transformation from gravity to pressurized irrigation systems. Pressurized irrigation does not always deliver real water savings at the farm, system and basin scales. For example, localized irrigation may increase net water use at the farm level as a result of intensification due to multiple cropping or enlarging the area under irrigation.

However, the adoption of pressurized irrigation often represents also a step forward towards better control, flexibility and accountability of irrigation water delivery, and therefore allows for transformation from low-return to high-return agriculture. Such transformations can therefore be justified not only in terms of water saving but in terms of increasing the productivity of irrigation. These considerations are discussed below, but in any case a clear understanding of changes in the distribution of water and implications at the level of the river basin or aquifer will always be needed.

Improving crop water productivity

Increasing agricultural water productivity, i.e. the amount of output per volume of water used, is widely accepted as the basic aim of irrigation. The Comprehensive Assessment of water management in agriculture (CA, 2007) provides an extensive review of this topic. Agricultural productivity can be raised either by increasing production from a given volume of water, or by reducing the volume of water while maintaining acceptable levels of production. The latter is the case of deficit irrigation, a strategy by which farmers apply less irrigation water than that needed to meet full crop water requirements. By accepting some yield losses in the major annual crops, deficit irrigation aims at achieving an economic optimum in the relation between water use and crop yields under water scarcity. Its application requires knowledge of the crop response to water deficits in the different stages of growth in order to formulate an irrigation schedule that maximizes water savings while it minimizes yield loss. Deficit irrigation is commonly used in permanent crops such as fruit trees or vines where, contrary to the situation with annual crops, reducing acreage or not planting are not viable options to respond to water scarcity. For many tree crops, deficit irrigation offers the possibility of reducing irrigation water use while maintaining farmer income in water-scarce conditions (FAO, 2012).

Raising crop yields, (production per unit of land) is the single most important source of crop water productivity increase. Over the last 30 years, yield increases accounted for 75 percent of the growth in agricultural production and it is expected that it will remain the main source of growth in agricultural production (FAO, 2006a). In irrigated systems, yield increase can be promoted through agronomic measures that maximize the part of water that is put into beneficial use through crop transpiration and minimize the part of water that is lost through non-beneficial evaporation. This does not necessarily imply an increase in water supply to the crops. Only a small fraction of additional water is captured as additional crop water content, but this fraction usually represents less than one percent of total water used by the plants. Therefore, any yield increase directly translates into crop water productivity improvement.

Plant breeding and biotechnology can help by reducing biomass losses through increased resistance to pests and diseases; vigorous early growth for fast ground cover and/or root development; and reduced susceptibility to drought.

Although substantial progress has been made in several water-scarce countries in reducing the gap between actual and potential yield of crops, much progress could still be made. Yield increases are made possible through a combination of water control, improved land management, seed material, and prudent use of fertilizers and plant protection chemicals. However, improved water control is a prime requisite for intensification and yield increase. In particular, there is a direct relationship between the reliability and flexibility of water supply and the capacity to invest in crop production.

Therefore wholesale modernization of irrigation schemes (a combination of infrastructure and managerial upgrades in a way that improves water delivery services) is likely to be central to national strategies aiming to increase the performance of crop production. Combined with soil fertility management and plant protection, modernization has the potential to substantially reduce yield gaps in irrigated production. With this in mind, FAO has developed several tools to evaluate the productivity of irrigated agriculture. The MASSCOTE (MApping System and Services for Canal Operation Techniques) approach assesses the performance of irrigation management by analysing and evaluating the different elements of an irrigation system in order to develop a modernization plan to improve water delivery services and cost-effectiveness of operation and management (FAO, 2007). AquaCrop is the FAO crop model to simulate yield response to water, which is particularly suited to address conditions where water is a key limiting factor in crop production. (FAO, 2012).

Re-allocating water from lower to higher value use in irrigation

The scope for increasing value per unit of water use in agriculture (economic water productivity) varies considerably, but in some cases it may be a more promising avenue than increases in physical water productivity. There is no correlation between crop water requirements and economic return. In water-scarce areas it makes sense to use water for crops providing a high economic return, rather than for staple crops with lower economic returns. In Tunisia, this aim is referred to as "*la meilleure valorisation économique de l'eau*"[15].

Where market conditions exist and staple production can be substituted from other sources, farmers can be encouraged to shift from lower value to higher value crops and increase the productivity of water in agriculture. However, higher value crops usually require more flexible and reliable water supply systems than what many large-scale public irrigation schemes can offer. This may call for changes in both the management and technology of irrigation – it is no coincidence that cash crop production is usually associated with groundwater, where farmers have full control over their water supply. High value crops are usually very capital-intensive and sensitive to market conditions, and more risky for farmers for these reasons. Shifting to higher value crops requires access to inputs including seeds, fertilizers and credit, as well as technology and know-how.

The extent to which national policies in water-scarce areas will focus on such conversion to productive agriculture will also be linked to national food security strategies. The level of integration of the country in the global economy, access to important markets through trade agreements and level of confidence in the global market for access to staple food are all factors that will condition national food strategies and affect the priority for the re-allocation of water to higher value uses. But, as pointed out in the earlier discussion of reducing water losses, it is possible for highly efficient and highly productive irrigated agriculture to simply exploit all sources of water. At this limit, few options remain but to set quotas on harvested areas and the volumes of evapotranspiration.

15 Information from the presentation by Tunisia at the Expert Consultation.

6.3 OPTIONS OUTSIDE OF THE WATER DOMAIN

Investing in rainfed agriculture

Rainfed agriculture represents 80 percent of land under cultivation, and contributes 58 percent of global crop production (Bruinsma, 2009). It is therefore the primary source of agricultural production at global level. This has prompted a broadening of the scope of agricultural water issues to include both irrigated and rainfed agriculture (Wani, Rockström and Oweis, 2008; Rockström *et al.*, 2009). The concept of blue water (water flowing in rivers, lakes and aquifers) and green water (rainwater stored in the soil and used directly by plants through evapotranspiration) has been promoted to show the relative importance of rainfed agriculture in relation with irrigation in terms of water use. In fact, freshwater consumed in irrigation represents only 20 percent of all the water consumed by crops through evapotranspiration (CA, 2007).

There are several reasons to invest in rainfed agriculture as part of a water scarcity coping strategy, but the opportunities vary greatly from one place to another. Where the climate is suitable for rainfed agriculture, there is great potential to improve productivity where yields are still low, as is the case in many regions of sub-Saharan Africa (CA, 2007). Here, a combination of good agricultural practices (through management of soil, water, fertility and pest control), upward (inputs, credit) and downward (markets) linkages, combined with weather insurance schemes can go a long way in improving agricultural productivity with little impact on water resources.

It is in the semi-arid tropics that the issue of balance between irrigated and rainfed agriculture gets most attention. In these areas, relying on rainfed agriculture involves considerable climate-related risk. A range of water-harvesting techniques have been advocated for bridging short dry spells, and thus decreasing risk in rainfed agriculture (Wani, Rockström and Oweis, 2008; Faurès and Santini, 2008). However, such techniques generally do not protect crops from longer dry spells that may lead to crop failure. Benefits, costs and risks associated with such practices must be carefully appraised in order to judge their appropriateness. In addition, semi-arid tropics have been identified as particularly vulnerable to climate change and associated climate variability (FAO, 2011a).

Reducing losses in the food chain

Losses occur all along the food chain, from harvesting to transportation, storage and packaging. Further losses occur in food processing, wholesale and retail trade, and in consumption by households. FAO (2011b) estimates that losses and wastage may be in the order of 30 percent between the field and end user. Clearly, part of these losses will be irretrievable following the progressive extension of the food chain associated with a modern economy. In a national food security strategy, however, it makes sense to carefully identify the major sources of losses and assess the potential for their reduction.

Associated with this is the question of diet, which is attracting increasing attention. As societies progress, per capita food consumption tends to increase and diets become more diversified (UN-Water, 2006b). Increasing consumption of meat and, to a lesser extent, dairy products places increased pressure on water, because of the large volumes of water entailed in their production (CA, 2007). The extent to which societies are willing and ready to modify their dietary habits as part of a larger effort to reduce their environmental footprint is beyond the scope of this report. It does, however, have implications for national food security and strategies to cope with water scarcity.

Beyond agricultural production: virtual water and the role of trade

In countries where water scarcity is a constraint to the achievement of self-sufficiency in food and other agricultural commodities, strategic choices need to be made on national food security policies and the role of agricultural trade.

The concept of 'virtual water' was developed in the 1990s (Allan, 2001; Hoekstra and Chapagain, 2007) to develop the link between international trade and water policy. Virtual water is the water used to produce a commodity: where these commodities are traded, virtual water also changes hands. Chile's economic development strategy, for instance, is based on the export of virtual water through copper, fruit, wood pulp, wine and salmon[16]. If a country has a scarcity of water to produce what it needs for national food security, it may be economically rational for it to import such produce, in return for goods and services that are less water-intensive. Buying food in world markets at times of local scarcity can also be kept as an option, provided the country has sufficient foreign exchange reserves and other means of access to international trade. It should be borne in mind that, in large countries such as China, with extreme climatic variations between regions, virtual water can apply to internal trade too[17].

The virtual water concept is subject to some technical caveats, one of which is that it does not distinguish between crops produced under rainfed conditions (where water is intrinsically linked to land and therefore 'free of charge') and crops produced with irrigation, where water definitely has a cost. In the case of meat, one has to keep in mind that free roaming animals are efficient collectors of 'virtual' water: in arid areas, the pasture they consumed grew on rainfall that usually would have no other use.

Although not expressed in hydro-centric terms, food trade and associated virtual water is a reality and will tend to increase as the number of countries reaching absolute water scarcity levels increases. However, according to empirical studies, the concept of virtual water does not appear to be widely practised. In an econometric sense, virtual water does not explain much of international trade. This does not impugn the basic principle, though it does suggest that other factors tend to predominate in determining the composition of international trade. Subsidies, foreign exchange shortages, a reluctance to rely on foreign supplies, and the presence of other powerful domestic forces all explain the limitations of the virtual water concept as an operational tool (Fraiture *et al*., 2004; Fraiture and Wichelns, 2010). Of particular concern to nations in the recent past is the need to maintain a certain level of food sovereignty. Fluctuating prices of basic food staples, and their impact on population, in particular in developing countries, induce decision-makers to review their food policy in favour of increased self-sufficiency. In places where water is scarce, such consideration does affect water policy and adds a political and social dimension to the narrower economic rationale associated with the concept of virtual water.

6.4 ISSUES OF SCALE AND INTER-DEPENDENCY OF RESPONSE OPTIONS

Not all response options are valid at all scales. Table 6 shows how the various options apply differently at river basin, irrigation scheme and farm levels, and beyond farm gates. It provides an opportunity to focus attention on the different stakeholders involved in the development of water scarcity coping strategies, and on the need to tailor programmes to the needs of these different stakeholders. It also highlights the

16 Information from the presentation by Chile at the Expert Consultation.

17 Information from the presentation by China at the Expert Consultation.

inter-dependency between options. In particular, options at farm level that aim at reducing on-farm water losses or increasing water productivity depend on the quality and reliability of water delivery service, which in turn depends on the type of irrigation infrastructure and equipment, and, eventually, on the management of water at river basin levels. As water flows from rivers to canals and to farmers' fields, so does the capacity to control it and no substantial improvement can be expected at farm level without improvements at higher levels.

TABLE 6
Scale of application of different response options

	Measure	River basin/aquifer	Irrigation scheme	Farm/plot	Beyond production
Supply-side options	Reducing inter-annual variability of river flow	Increased storage (multi-purpose dams)	On-scheme water storage	On-farm water conservation	-
	Enhancing groundwater supply capacity	Groundwater development, management and artificial recharge			-
	Water recycling and re-use	-	Re-use of urban wastewater for crop production		-
	Pollution control	Basin - level monitoring, regulation and incentives for pollution control	-	Integrated plant production and protection	-
	Importing water	Inter-basin transfers	-	-	-
Demand-side options	Reducing water losses	Improved water allocation planning	Pressurized conveyances of water, improved irrigation scheduling and distribution and canal lining	Pressurized application of water (drip), improved irrigation scheduling and moisture control	-
	Increasing water productivity	Better water management mechanisms, enhanced predictability of supply, early warning	Yield gap reduction through improved agricultural practices	-	-
	Water re-allocation	Intersectoral transfer (through water markets or other water allocation mechanisms)	Scheme-level water transfer mechanisms	Shift to higher value crops in irrigation, restraining cropped area under irrigation	-
	Reducing losses in the value chain	-	-	Reduction in crop losses through pest control	Reduction post harvest losses in storage, processing, distribution, and final consumption
	Reducing demand for irrigated products and services	-	-	Reduced yield gap in rainfed production	-
	Reducing water use per capita	-	-	-	Changes in food consumption patterns (less water-intensive diets)

6.5 THE FOOD SUPPLY COST CURVE AS A TOOL FOR DECISION-MAKING

The foregoing sections have discussed the range of options available to decision-makers to address the issue of food security in a context of water scarcity. Of particular relevance are the questions of supply enhancement versus demand management, and of the relative roles of rainfed and irrigated production in satisfying future demand for food and other agricultural products. Water plays a central role in these debates, both as major production factor for irrigated (and rainfed) systems and as a resources subject to competition with other use sectors.

Applying a cost curve to food supply strategies

The role of water in national food security strategies must therefore be examined in a critical way to ensure that all resources are managed in an efficient and sustainable way. The concept of “food supply cost curve” is a useful tool to support decision making in this field. It provides insight into the way a country can bridge its food supply gaps in a cost-effective way. Gaps in food supply can be defined as the difference between the current level of food supply and a desired or planned level food supply in the future that takes into account population growth and changes in dietary habits (the concept can be extended to non food agricultural products).

Domestic food supply at national level can be represented by the following equation:

$$FS = FP + I - E - L$$

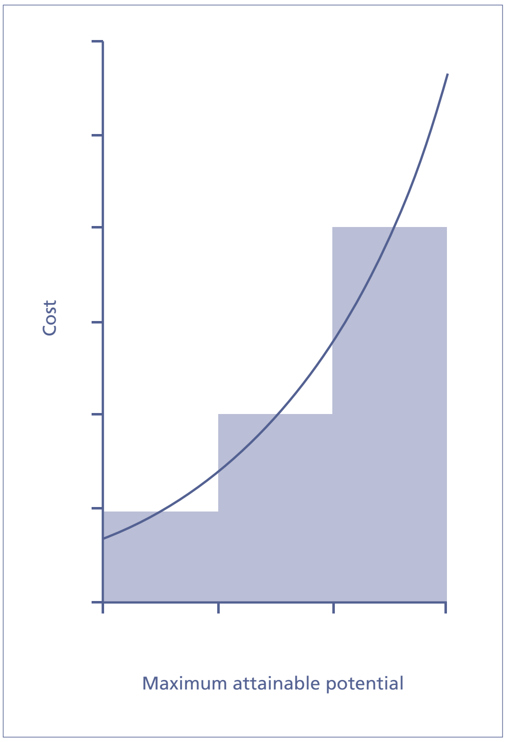
where FS = food supply; FP = food production; I = imports; E = exports; and L = Losses in the food chain.

A comprehensive assessment and projection of food demand requires that demand be broken down in major food products, including meat, fish and dairy products. Here, we focus on major food crops (considering that demand for meat and dairy products can be expressed in terms of feedstock and therefore in terms of crops). There are only three possible sources of growth for future crop production (Bruinsma, 2009): increase in yield; increase in cropping intensity; and expansion of cultivated areas. Increase in crop production can therefore be expressed as a function of these three sources of growth. Since the modalities and costs involved in managing, upgrading or expanding land under rainfed and under irrigated conditions are different, it is important to consider these options separately, and as all three sources of growth can apply to both rainfed and irrigated agriculture, there are in total six variables which can be influenced to reach a given level of crop production. Adding to this an element of reduction in losses in the food chain, and food trade (imports or exports), policy-makers have a total of eight options that they can combine to reach domestic food supply goals.

For each of these options (with the exclusion of trade), a potential contribution to the domestic food supply goal can be calculated on the basis of maximum attainable yield for major crops, availability of land and water resources, and potential reduction in food losses. Typically, each of these options will have an exponential cost distribution of the shape shown in Figure 5.

This cost distribution reflects the fact that early gains are easier and therefore less costly to obtain than those closer to the ultimate potential. For example, if one considers rainfed cropping with low inputs and low yields, it is relatively easy to increase

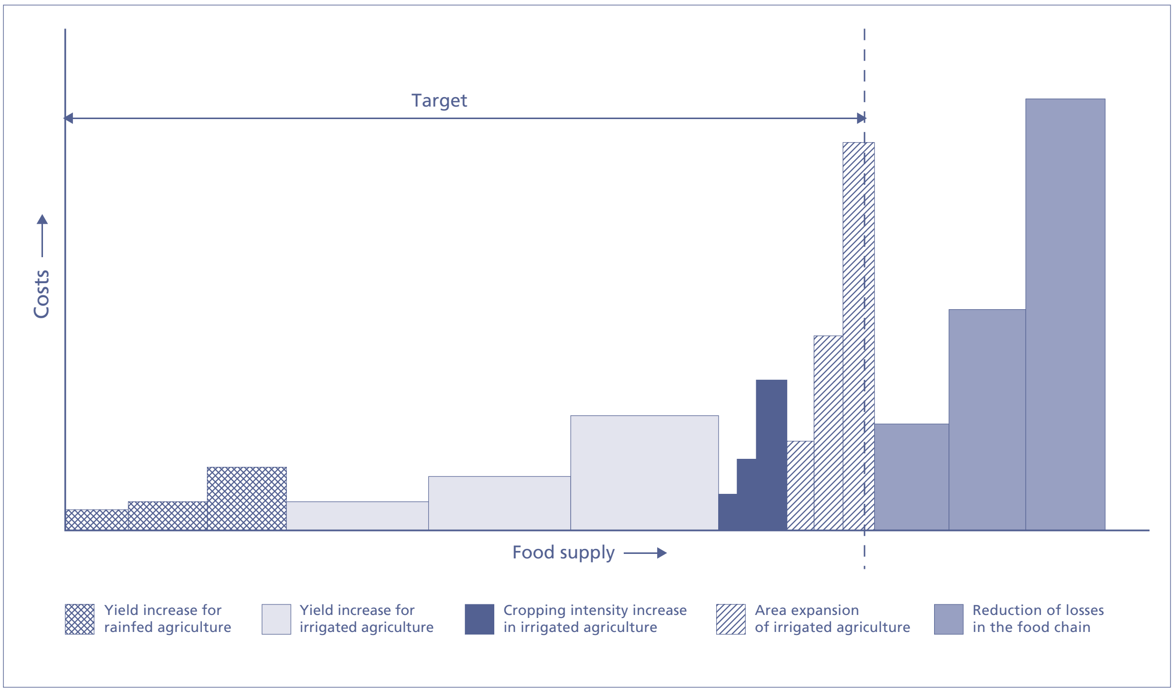
FIGURE 5
A typical cost curve for a given response option



yields by implementing measures like weed control, improved soil fertility management or improved seed material. Increasing yields further will become more difficult and costly with measures like developing better market conditions or investing in agricultural research and extension. To increase yields even further, expensive measures become necessary, such as full mechanization for precision agriculture. This is as valid for yield increase, as it is for expansion of cropland and of irrigation water supply, or for the reduction of losses in the food chain. In the graph in Figure 5, the cost curve is simplified and represented in three blocks of increasing costs. It is also the case for food import, as food cost in the international market depends on the capacity of a country to predict its food requirements, and last minute adjustments are usually more expensive than early deals.

On the "food supply cost curve", the x-axis represents the amount of extra food that can be obtained from these different options, while the y-axis shows the costs involved per option. Each country will have its own curve, based on current level of intensification, availability of land and water, and level of losses in the food chain. Figure 6 represents an example of a country that strives for food self-sufficiency with no more land available for rainfed agriculture.

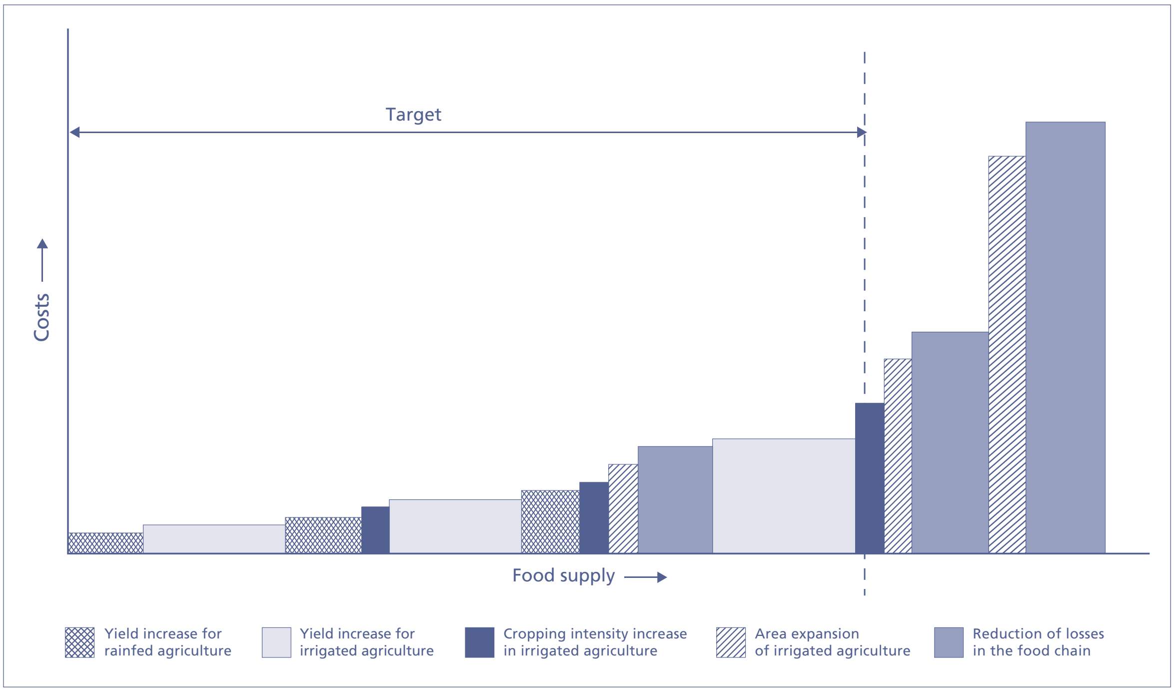
FIGURE 6
Options available to increase food supply and their associated costs at national level – a case of a country where all land resources are already in use and expansion is not foreseeable.



The sources of growth for food production in Figure 6 are yield increases in rainfed and irrigated agriculture; increased cropping intensities in irrigated agriculture; expansion of irrigated areas (from previously rainfed land – a typical pattern of intensification); and reduction in losses in the food chain. The costs to implement increases in food supply from each of the categories are not uniform, as indicated by the height of the bars. For each of the categories, specific measures should be identified that can be taken to increase domestic food supply. In the category “expansion of irrigated areas”, one could first think of extending existing irrigation schemes as a relative cheap measure, increasing the use of groundwater for irrigation could be imagined as an intermediate measure, while the most expensive measures would be obtained through the construction of additional reservoirs and inter-basin transfer, and the development of additional irrigation in marginally suitable locations. Similarly, parts of the post-harvest losses in developing countries can be reduced through relatively easily implementable measures, like better harvesting techniques or better food storage on the farm and at community level. More demanding measures might include better access to markets and market information; improved infrastructure for better transportation; and improved storage, processing and packaging technologies. The food supply cost curve is obtained by ranking the options by growing level of cost. Figure 7 shows the most cost-effective combination of options that would be needed to fill a given food supply gap.

FIGURE 7

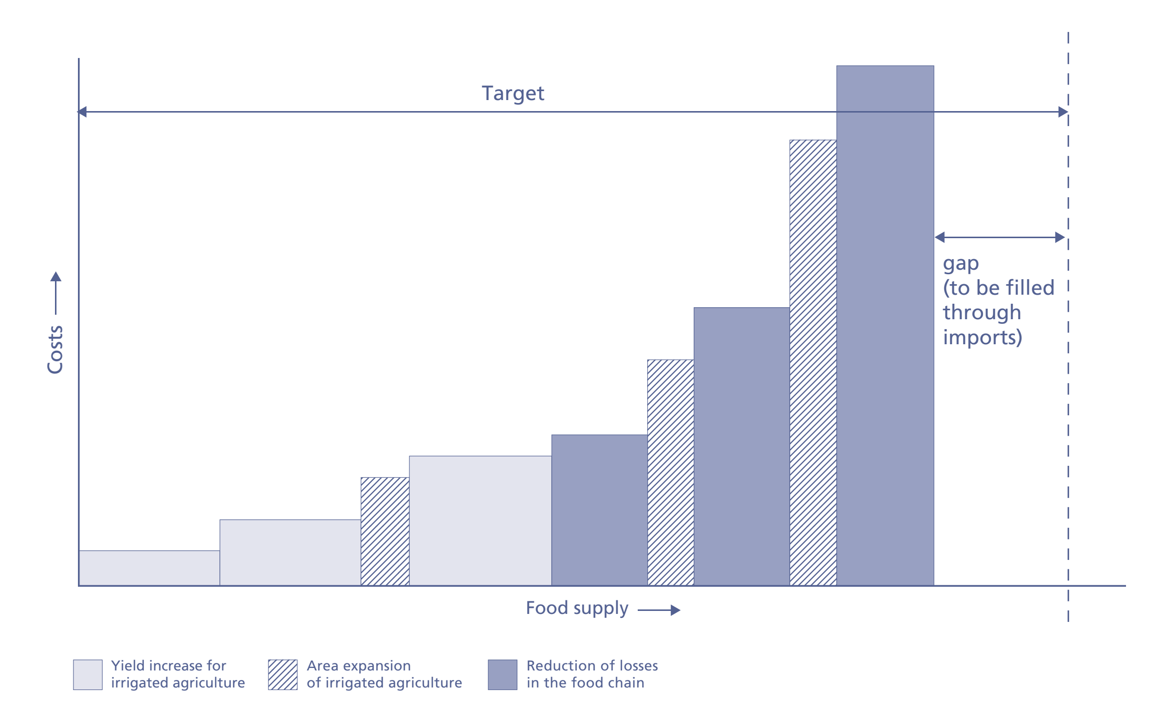
Food supply cost curve – the case of a country where all land resources are already in use



The options available per category are different for every country, and so are their associated costs. The measures that could be taken at the right-hand side of the graph are the most expensive ones, and could possibly be avoided if food would be imported. This can be made clearer with Figure 8, an example of a food supply curve of a country where resources are not sufficient to satisfy domestic needs.

The country from the example of Figure 8 can only produce food under irrigation. Agriculture is already intensive and there are no opportunities to increase cropping

FIGURE 8
Example of a food supply cost curve – the case of a resources-scarce food-deficit country



intensities. The sources of growth to increase production are yield increases and possibly expansion of irrigated areas. The graph shows that it is impossible for this country to be self-sufficient in domestic food supply. Some food supply savings can be made by reducing losses in the food chain, but many options in this category are often considered to be too expensive. The graph shows that part of the food supply gap will need to be met through import from the international market. In many cases, the cost of food in the international market is cheaper than the most expensive national food supply options, and this will have to be negotiated internally, taking into account broader policy concerns over food sovereignty and national food security.

Calculating the food supply cost curve

The cost curve described earlier provides a simple but powerful method for identifying and ranking options for food production in conditions of water scarcity. Much of the complexity lies in the establishment of the individual cost curves for the different options and requires a good understanding of the agronomic, hydrological and socio-economic conditions in which improvements will take place.

Yield increase, for instance, will in most case be the result of a combination of agronomic and economic improvements, which can hardly be considered separately. While in general there is always a main limiting factor, it is a combination of good agricultural practices that will contribute to yield increase rather than any of these practices considered separately.

Another dimension of relevance in the establishment of the cost curve is the level of uncertainty associated with production under rainfed and irrigated conditions. The level of uncertainty is typically higher in rainfed than in irrigated agriculture, given the exclusive reliance on rainfall for water supply, with variations between countries or within countries as a function of prevailing climatic characteristics. Such risk associated with production must be captured in the cost curve, and plays an important role in the decision-making process.

The same applies to food import, and the risk associated with food price volatility in the international market. This risk can be dealt with by increasing supply storage, making exclusive long-term contracts to produce food outside the country, or making early deals in the world market. The cost-effectiveness of all these option can be analysed through the food supply cost curve.

Finally, the cost curve is subject to many possible levels of refinement that will affect decision-making. The cost of a given option can be considered in economic terms only, but it can also be expanded to capture the environmental, social and political dimensions that are needed for informed decision-making.

7. Principles for action

Section 6 described the variety of options available to different types of decision-makers to address the challenge of water scarcity and the role of agriculture. The choice of options and their relative potential will depend on a series of conditions, including local agro-climatic factors, levels of water scarcity, the role agriculture plays in national economies, and societal values. It will also depend on external factors, including the global trade and cooperation environment, and the prospects for climate change. Furthermore, in view of the rapid changes in the geo-political, societal and environmental fields, what could be considered an optimal option today may no longer be valid tomorrow. No blueprint approach is therefore possible, and it is unlikely that a single set of options can be designed as the 'optimal' solution, nor is a particular option to be seen as desirable – or possible – in all contexts.

It is, however, clear that 'doing nothing' results in environmental degradation, sub-optimal use of scarce resources, inequity in access to these resources, and costs to the economy and social welfare, which can lead to conflict at all levels, from the farm to the international river basin.

Since strategic solutions to water scarcity are by their nature case-specific, this concluding section proposes some generic principles that are valid for different socio-economic settings. Six basic principles have been developed and are discussed below. Together, they represent the necessary starting point for any effective, efficient and sustainable strategy to cope with water scarcity in agriculture.

7.1 KNOWLEDGE: BASE STRATEGIES ON A CLEAR UNDERSTANDING OF THE CAUSES AND EFFECTS OF WATER SCARCITY

Coping strategies should be founded on a good understanding of the causes of water scarcity, both nationally and locally. A detailed accounting of water supply and demand should be used as the starting point, and the basis for identifying, adapting and developing coping strategies. This should recognize that that there are limits to the water than can be exploited, and that there might be multiple causes for water scarcity (on either demand or supply sides), all of which vary in time and space. It is also important to understand linkages with the different sectors of the economy, as the prime causes of water scarcity are likely to lie outside the water domain (e.g. economic or agricultural policies that encourage unsustainable use of water resources). It is therefore important to base strategies on the best evidence available and not rely purely on hearsay or intuition (though these might provide useful insights).

The importance of understanding the hydrological cycle when designing water policies has been stressed in Section 5. The interrelationship between surface water and groundwater, between upstream and downstream catchments, between quality and volumes, and the importance of water re-use within river basins – all these have implications for the effectiveness of proposed actions. Water accounting provides a sound basis for evidence-based strategy development and adaptation, as more evidence becomes available. A failure to understand the hydrological implications of proposed actions may lead to unexpected consequences, and well intentioned, but ill-informed, strategies for coping with water scarcity can have perverse impacts on the way water is distributed within the river basin, without achieving the expected savings.

Integrated planning offers opportunities for enhanced management of water demand. Where water is scarce, particular attention should be paid to the re-use potential of recoverable non-depleting uses at every stage of planning, designing and implementing multipurpose water supply and use schemes (UN-Water, 2009).

7.2 IMPACTS: ASSESS THE FULL RANGE OF BENEFITS AND COSTS, AND USE SYSTEMATIC AND COMPREHENSIVE DECISION CRITERIA

Cost-benefit and cost-effectiveness criteria have a crucial role in the choice of options, alongside other criteria such as equity, environmental impact and other collective social values. It is, however, difficult for cost-benefit analysis (CBA) to fully and accurately capture all the potential impacts of water projects on people or on the environment, and there has been a tendency to overestimate net benefits, especially for major infrastructure. CBA techniques are malleable and have not proven to be sufficient in themselves to instil better planning practices, according to Molle (2003).

Cost-effectiveness analysis (CEA) may appear simpler, insofar as benefits do not need to be directly estimated. But CEA is also multi-dimensional, and the parameters of a specific case can change over time with developments in our understanding of social and environmental processes and values, and the differential economic development of different sectors. A valid option 20 years ago in a certain place may today no longer be valid. Increasing concern and improved knowledge about the construction of large dams is a case in point (World Commission on Dams, 2000).

Supply and demand management options come with attendant costs and benefits that have different spatial and social distribution. The respective distribution of benefits between private and collective interests will depend on the governance context, such as the process of decision-making, and its intrinsic transparency and accountability. These points are taken up in the next section.

In terms of food supply, the cost curve discussed in Section 6 represents a valid option for cost-effectiveness analysis, where considerations of inter-dependency and inter-connectedness of options are clearly taken into account and backed by a careful review of water-related implications of feasible options. It does offer a useful way to rank interventions according to their cost-effectiveness and assess the cost of different combinations of options.

7.3 CAPACITY: ENSURE THE RIGHT LEVEL OF WATER GOVERNANCE AND INSTITUTIONAL CAPACITY IS IN PLACE

As supply enhancement reaches its limits in an increasing number of regions, demand-management options become more prominent in coping with water scarcity, which calls for stronger and more effective institutions. Water scarcity will also arouse tensions between users, with the likelihood of negative impacts on politically weak and marginal social groups and on the environment. Strong institutions will be needed to guarantee equitable distribution of benefits among different categories of water users.

The growth of such institutions is still a major challenge (Pritchett, Woolcock and Andrews, 2010). A more 'contextualized' distribution of roles and responsibilities; empowerment of local institutions, including users groups; review of policies; adaptation of laws; and the use of incentive mechanisms such as subsidies and taxes – all are relevant (Rogers and Hall, 2003), but the application of universal models or panaceas appear to have had little impact (Meinzen-Dick, 2007; Merry and Cook, 2012). It should be asked, though, why dysfunctional bureaucracies or interest groups would reform themselves. Corruption, a lack of transparency and poor accountability are reasons for poor performance, resistance to change and inequitable delivery of services. In reality, effective changes tend to be triggered by shocks external to the institutions themselves, such as major policy changes at the top, or by the mobilization of civil society (and democratization of society at large), rather than from internal reforms alone.

Existing management strategies may cease to be viable as the nature or severity of water scarcity changes over time, or because the institutional and legal context is no longer adapted to current conditions. Laws cannot be enforced only through negative sanctions: positive incentives are required, as well as efforts to instil a new culture of water management. This includes public awareness campaigns and school educational programmes. It also calls for capacity building and training in traditional water bureaucracies and at intermediate and local levels of administration, where institutions are often weak and ill-prepared to cope with change (Mathew and Le Quesne, 2009).

Water scarcity will pose particular challenges to the management of large irrigation schemes. This will require the definition, allocation and monitoring of volumetric entitlements or quotas that are sufficiently flexible to protect the social environment and essential economic interests under conditions of fluctuating supply and increasing scarcity (Hodgson, 2006). Such a regime will not be easy to establish, and will require sophisticated measurement and monitoring of water flows.

Institutional change is likely to entail greater managerial collaboration and partnership between public, private and other agents. Where reforms involve the public sector withdrawing from operational tasks, public supervision becomes critical. In this context, the precise status and location of regulators within the administration is a crucial issue, but experience shows that one does not easily modify pre-existing patterns of bureaucratic power.

Improved governance also has implications for financing. Realistic funding streams are required for the full life-cycle costs of water scarcity initiatives and programmes. In many cases, this involves putting less emphasis on capital costs of construction and engineering and more emphasis on capacity building, stakeholder-based planning, operation and maintenance, and other long-term institutional support costs.

7.4 CONTEXT-SPECIFICITY: ADAPT RESPONSE TO LOCAL CONDITIONS

The response of a country to water scarcity depends very much on the country's specific physical and socio-economic conditions. At a national level there is little correlation between GDP and water scarcity, though there is a link between GDP and the availability of response options. Richer countries have more options to adapt to water scarcity than poor countries: desalination is an affordable option for Saudi Arabia, though not, on the same scale, for less affluent countries in the same region like Egypt or Yemen. The feasibility of options will also depend on the cost of capital and labour, and the role of agriculture in the economy. Poor countries where agriculture is a major sector in the economy have fewer opportunities than others to cope with water scarcity without having major impacts on the economy and people's livelihoods.

Countries and regions greatly differ in the rate of exploitation of their water resources. Countries such as Iraq and Uzbekistan withdraw much more water per person than other similarly water-scarce countries. In such countries, the policy emphasis will necessarily be much more on demand management, compared with countries with lower levels of water scarcity. In short, the range of options for dealing with water scarcity varies according to economic and physical circumstances.

7.5 COHERENCE: ENSURE POLICY ALIGNMENT FOR WATER, AGRICULTURE AND FOOD SECURITY

Policies, legislation and fiscal measures have profound effects on what happens at district and local levels, most importantly in setting boundaries for stakeholder involvement in decision-making, and in clearly articulating their roles and responsibilities (Moriarty *et al.*, 2008). It is crucially important that there is good alignment among the many policies, items of legislation and fiscal measures that influence water management, service delivery and level of demand. Decisions outside the water domain, such as those concerning energy prices, trade agreements, agricultural subsidies and poverty reduction strategies, often have a major impact on water supply and demand, and hence on water scarcity.

Agriculture and food security are intimately linked to water, and therefore policies in these domains must be consistent. In times of crises, and with volatile markets, concerns about feeding their populations become of paramount concern to national decision-makers. Water authorities should cease to regard water as a sector 'compartment' and engage more proactively with other economic sectors to make their strategies for coping with water scarcity coherent with key decisions being taken elsewhere (UN-Water, 2009). Such inter-sectoral dialogue is essential for 'operationalizing' the concept of Integrated Water Resources Management.

7.6 PREPAREDNESS: ANTICIPATE CHANGES THROUGH ROBUST DECISION-MAKING AND ADAPTIVE MANAGEMENT

The drivers of change for water are accelerating, forcing decisions to be taken against increasing uncertainty. One such driver – climate change – creates increased frequency and intensity of extreme events, requiring more resilience from people and society. The concern now is that the scope for incremental change in coping strategies may be reaching its limits because changes in supply and demand may be too rapid for effective adaptation.

There is a risk of coping strategies being derailed by external factors and changes occurring that are outside the control of those involved in developing and implementing these strategies. These external risk factors include climate change, the global financial and economic situation, and the system of international governance in which countries function. In this context, scenario building is an integral part of strategy development, forming a means of identifying, limiting or mitigating these risks. Risks are becoming increasingly difficult to predict. As a consequence, it makes little sense to try to develop optimum strategies, and what is needed is continuous evaluation and adaptation of strategies.

Water professionals have developed effective approaches to deal with the uncertainty associated with the stochastic nature of climate, but they are now facing increasing difficulties in planning and managing water under increasing uncertainty of both supply and demand. The concepts of robust decision-making (Groves, 2006) and adaptive management turn many debates on water management on their head by recognizing that it is very difficult to predict future patterns of supply and demand with any great confidence (Moench, Caspari and Dixit, 1999). This being the case, management systems need to be flexible, able to adapt to new challenges, and be based on continuous social and institutional learning. Robust decision-making makes extensive use of scenarios to work out decisions that are robust under a variety of alternative futures. Adaptive management accepts that in complex situations there can never be sufficient information to come to an 'optimum' decision. It therefore puts the emphasis on flexible planning, backed by strong monitoring and information management systems that allow constant adaptation and the periodic upgrading of plans and activities. Such a level of responsiveness is only possible if information and knowledge are updated, and if monitoring and evaluation systems continually provide decision-makers with reliable information on which to base these response decisions. The adaptation policy framework (UNDP, 2004) offers a similar approach specifically targeted at uncertainty due to climate change.

Improving the resilience of water users to shocks and extreme events is a vital part of an effective coping strategy. Given that there is a risk that the frequency and magnitude of extreme events will increase, scenario-based approaches should be taken to planning resilience. In practical terms, a resilient coping strategy is one that has the potential to be effective under the largest possible range of scenarios developed during risk analysis.

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Annex 1. Definitions

The following definitions have been used in this report:

Absolute water scarcity. An insufficiency of supply to satisfy total demand after all feasible options to enhance supply and manage demand have been implemented. This situation leads to widespread restrictions on water use. A threshold of 500 m^3/ person/yr is often used as a proxy to indicate absolute water scarcity (Falkenmark, 1989). It is held here to apply in terms of water quantity alone, although in many cases water quality may also impose scarcity if it is not fit for consumption.

Available water. That part of water resources that is available for use. The concept is ambiguous, and depends on whether it refers to water available for immediate use or freshwater resources available for future development. In either case, access to the water would have a cost.

Beneficial consumption of water (in agriculture). The part of water that is withdrawn from its source for the purpose of irrigation and which is either consumed by crops through transpiration or captured as biomass. Non-beneficial consumption is the part of water withdrawn from its source which evaporates from the soil without contributing to biomass production.

Beneficial use of water. The use of water for purposes that have clear and tangible benefits, such as for household purposes, irrigation, industrial processing and cooling, hydropower generation, recreation and navigation. Depending on context, beneficial use may also include maintaining river levels for environmental purposes, diluting wastewater flows and sustaining wetlands, preventing saltwater incursions in estuaries, etc.

Chronic water scarcity. The level at which all freshwater resources available for use are being used. Beyond this level, water supply for use can only be made available through the use of non-conventional water resources such as agricultural drainage water, treated wastewater or desalinated water, or by managing demand. A range between 500 and 1 000 m^3/person/yr has often been used as a proxy to indicate chronic water scarcity (Falkenmark, 1989).

Consumptive use of water. The part of water withdrawn from its source for use in a specific sector (e.g. for agriculture, industry or domestic purposes) that will not become available for re-use because of evaporation, transpiration, incorporation into products, drainage directly to the sea or evaporation areas, or removal in other ways from freshwater sources. The part of water withdrawn that is not consumed in these processes is called return flow.

Cost of water. In a restricted sense, the cost of water relates to the direct expenses incurred in providing the service of water supply. Full supply cost includes operation and maintenance costs, and capital depreciation and replacement costs. An assessment of the full cost of water to society should include, in addition to supply cost, its opportunity cost (i.e. the benefits foregone when water is not applied to its most beneficial use), and both economic and environmental externalities associated with water supply (indirect consequences that are not directly captured in the accounting system) (FAO, 2004; GWP, 2000). The cost of a water service may need to be distinguished from its ‘price’ as revealed through market transactions, where they exist, and its economic value (see definition of water pricing and water values).

Demand management. A set of actions consisting in controlling water demand, either by raising the efficiency of its use (see definition below) or re-allocating water between or within sectors.

Exploitable water (also called **manageable water resources** or **water development potential**). The volume of water potentially available for consumptive water-use sectors (agriculture, industries or municipalities). An attempt to quantify that part of a country’s *total renewable water resources* that is effectively available to be withdrawn, depending on factors such as the economic and environmental feasibility of water storage; extracting groundwater; maintaining flow requirements for navigation and environmental services; etc. The level of exploitable water varies with the level of the country’s economic development, infrastructure, water variability and quality, and the trade-offs between rival users.

Freshwater. Naturally occurring water on the Earth's surface in glaciers, lakes and rivers, and underground in aquifers. Its key feature is a low concentration of dissolved salts. The term excludes rainwater, water stored in the soil, untreated wastewater, seawater and brackish water. In this report, when not otherwise specified, the term *water* is used as synonym for freshwater.

Institutions. The laws and regulations governing the management, development, protection from pollution, and use of water resources; the governmental bodies at all levels, in charge of the administration and enforcement of the laws and regulations; the judiciary; and the formal or informal water users-level organizations.

Modernization. In irrigation, modernization is defined as a process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation schemes, combined with institutional reforms, if required, with the objective to improve resource utilization (labour, water economics, environment) and water delivery service to farms (FAO, 1997).

Return flow. The part of the water withdrawn from its source which is not consumed and returns to its source or to another body of groundwater or surface water. Return flow can be divided into non-recoverable flow (flow to salt sinks, uneconomic groundwater or flow of insufficient quality), and recoverable flow (flow to rivers or infiltration into groundwater aquifers).

Supply enhancement (also called **supply management** or **supply augmentation**). A set of actions to increase water supply, either through water resources development (construction of water infrastructure or groundwater development) or augmentation of available water resources through development of *non-conventional* sources of water, such as desalination of sea water or re-use of treated wastewater.

Total renewable water resources. The long-term annual average sum of internal and external renewable water resources within a specified domain. It corresponds to the maximum theoretical yearly amount of water actually available for a country without considerations of water quality and environmental requirements. *Internal*

Renewable Water Resources for a country are defined as long-term average annual flow of rivers and recharge of aquifers generated from endogenous precipitation. *External Renewable Water Resources* are defined as the part of the country's annual renewable water resources that are not generated in the country. It includes inflows from upstream countries and part of the water of border lakes or rivers. It takes into account the quantity of flow reserved by upstream (incoming flow) and/or downstream (outflow) countries through formal or informal agreements or treaties, and possible water withdrawals occurring in the upstream countries.

Water accounting. A systematic method of organizing and presenting information relating to the physical volumes and flows of water in the environment as well as the economic values of water through cost-benefit analysis.

Water audit. A systematic study of the current status and future trends in both water supply and demand, with a particular focus on issues relating to governance, institutions, finance, accessibility and uncertainty in a given spatial domain.

Water charges. The term refers to the payments that a beneficiary makes for a water service (domestic supply, irrigation, etc.). The action of establishing the price, or tariff, on the basis of which water charges are calculated is often referred to as *water pricing* but is clearly very different from the formal economic ‘pricing’ of water as a natural resource, where the notion of *shadow pricing* applies (see *water pricing* below)

Water conservation. The protection and efficient management of freshwater resources to ensure their long-term sustainability.

Water demand. In economic terms, the ability and willingness of users to pay for water and the services it provides. In this sense, water demand differs from water as a basic human need, requiring a minimum amount of safe supply. In the context of water scarcity, water demand is an expression of water requirement or need with a fair cost for a given water supply service level.

Water pricing. The action of establishing a price for a water service. The price can be calculated to cover all or part of the costs of the water service (see definition of cost of water), or to induce a change of behaviour in water use through less wasteful water use. In irrigation, it can be calculated per area of land, per type of crop, or on a volumetric basis. The price assigned to a water service is often called water tariff and may, or may not, reflect the economic value of the water resource itself. Even when market prices are revealed in local water transactions or regulated water markets (California, Chile, Australia) such prices may not reflect full economic values. Therefore in water resource planning, cost-benefit analysis needs to adjust observed prices or estimate prices altogether. These adjusted or estimated prices are commonly referred to as shadow prices.

Water productivity. The quantity (mass, calories) or value of output (including services) in relation to the volume of water used to produce this output. Crop water productivity is simply the amount (kg or calories) or value of product per unit of water supply (cubic metre).

Water resources assessment. Water resources assessment focuses on the supply side of water accounting and provides a systematic assessment of water resources, including their variability and trends.

Water scarcity. An imbalance between supply and demand of freshwater in a specified domain (country, region, catchment, river basin, etc.) as a result of a high rate of demand compared with available supply, under prevailing institutional arrangements (including price) and infrastructural conditions. Its *symptoms* are: unsatisfied demand, tensions between users, competition for water, over-extraction of groundwater and insufficient flows to the natural environment. *Artificial* or *constructed* water scarcity refers to the situation resulting from over-development of hydraulic infrastructure relative to available supply, leading to a situation of increasing water shortage.

Water shortage. A shortage of water supply of an acceptable quality; low levels of water supply, at a given place and a given time, relative to design supply levels. The shortage may arise from climatic factors, or other causes of insufficient water resources, a lack of, or poorly maintained, infrastructure; or a range of other hydrological or hydro-geological factors.

Water stress. The symptoms of water scarcity or shortage, e.g. widespread, frequent and serious restrictions on use, growing conflict between users and competition for water, declining standards of reliability and service, harvest failures and food insecurity.

Water supply. The amount of water which is available or made available for use.

Water tariff. See water pricing. Water tariffs vary widely in their structure and level between user categories, service providers and between countries and regions. The mechanisms to adjust tariffs also vary widely.

Water use. Any deliberate application or utilization of water for a specific purpose. There is an important distinction between *consumptive use* (see earlier definition) and *non-consumptive* use. Important non-consumptive uses include navigation, recreation, waste assimilation and dispersion. Although hydropower and power station cooling are not a major net consumptive user of water, they do have a major impact on the hydrological cycle, and release water at times and temperatures that impose costs on other water users. Reservoirs also cause evaporation losses.

Water use efficiency. In engineering terms, water use efficiency is the ratio between the amount of water actually used for a specific purpose and the amount of water withdrawn or diverted from its source, such as a river, aquifer or reservoir, to serve that use. It is dimensionless and can be applied at any scale. In this report, 'efficient use of water' is understood in more general economic terms, as the use of water to maximize the production of goods and services. Efficient use of water in agriculture can be pursued by reducing water losses in transmission and distribution, increasing crop productivity or diverting water towards higher value crops (intrasectoral allocation). But just because an agricultural use of water becomes more efficient does not mean that water is 'saved'. In the quest for greater 'efficiency', it is important to take a broad view (e.g. at basin level), recognizing the contribution that so-called 'losses' can make to the productivity of other users and in other parts of the water cycle.

Water use right. In its legal sense, a legal right to abstract or divert and use water from a given 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 or maintain water in a natural state (ecological flow in a river; and water for recreation; religious or spiritual practices; drinking, washing and bathing; or animal watering).

Water values. The benefit(s) of water from its use in specific purposes, locations and times. Many of these benefits can be quantified and valued in economic terms (e.g. for irrigation, industrial processing and, in many cases, household use), while others have to be expressed in a qualitative manner (e.g. amenity values). Direct water valuation techniques rely on questionnaires to elicit preferences on willingness to pay for a good or service (e.g. contingent valuation). Indirect water valuation techniques rely on observed market behaviour to deduce values (e.g. hedonic pricing, travel cost method).

Water withdrawal. Gross volume of water abstracted from streams, aquifers or lakes for any purpose (e.g. irrigation, industrial, domestic, commercial).

Annex 2.
Agenda of the Expert Consultation

Time	**Day 1: Monday 14 December**	**Day 2: Tuesday 15 December**	**Day 3: Wednesday 16 December**
8.45-9.00	Registration	Country presentation: Australia and Tunisia	Country presentation: China and Spain
9:00-9:15		Group session 2: Identification of main decision makers, response options, and conditions.	Group session 5: Focus for FAO action and partnership
9:15-9:30	Welcome address and objective of the meeting		
9:30-10:00	Introduction of participants (Johan Kuylenstierna)		
10:00-10:30	Presentation of draft conceptual framework (Pasquale Steduto)	Plenary: Summary of group findings	Plenary: Summary of group findings
10:30-11:00	**Coffee / Tea break**	**Coffee / Tea break**	**Coffee / Tea break**
11:00-12:15	Discussion on conceptual framework, including terminology (introduced by Jean-Marc Faurès)	Group session 3: Putting agricultural water scarcity in a broader perspective	Wrap-up: recommendations for future action
12:15-12:30		Plenary: Summary of group findings	Close
12:30-13:30	**Lunch**	**Lunch**	**lunch**
13:30-13:45	Country presentation: Egypt and South Africa	Country presentation: USA and Chile	
13:45-15:00	Group session 1: review of water scarcity concept, dimensions and causes	Group session 4: Criteria and principles for action	
15:00-15:30	Plenary: Summary of group findings	Plenary: Summary of group findings	
15:30-16:00	Coffee / Tea break	Coffee / Tea break	
16:00-16:30	Water audit: an approach to systemic assessment of water use (Charles Batchelor)	Remote sensing applications to water use assessment (Wim Bastiaansen)	
16:30-17:30	Discussion: application of water audit concept	Discussion: application of remote sensing in water audits	
17:30-18:00	Wrap-up	Wrap-up	

Annex 3.
List of participants of the Expert Consultation

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Guido Santini
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Annex 4.
List of presentations at the Expert Consultation

Coping with water scarcity
The role of agriculture. A framework for action
Pasquale Steduto

Water and agriculture in Australia
Mary Harwood

Coping with water scarcity
The role of agriculture. The case of Chile.
Humberto Peña

Water and agriculture in China
Mei Xurong

Some experiences of agricultural water use in China
GAN Hong

Coping with water scarcity: an Italian case study
Nicola Lamaddalena

Remote sensing of water consumption
in basins and agricultural systems
Wim Bastiaanssen

Coping with water scarcity in South Africa
Rivka Kfir

Coping with water scarcity in Spain:
current measures and future developments
Consuelo Varela-Ortega and Elias Fereres-Castiel

Water accounting - an approach to systematic
assessment of water use
Charles Batchelor

Water scarcity in agriculture – The case of Tunisia
Netij Ben Mechlia

Coping with water scarcity - US experiences
Mark Svendsen

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2 Irrigation water delivery models, 1994 (E)
3 Water harvesting for improved agricultural production, 1994 (E)
4 Use of remote sensing techniques in irrigation and drainage, 1995 (E)
5 Irrigation management transfer, 1995 (E)
6 Methodology for water policy review and reform, 1995 (E)
7 Irrigation in Africa in figures/L'irrigation en Afrique en chiffres, 1995 (E/F)
8 Irrigation scheduling: from theory to practice,1996 (E)
9 Irrigation in the Near East Region in figures, 1997 (E)
10 Quality control of wastewater for irrigated crop production, 1997 (E)
11 Seawater intrusion in coastal aquifers – Guide lines for study, monitoring and control, 1997 (E)
12 Modernization of irrigation schemes: past experiences and future options, 1997 (E)
13 Management of agricultural drainage water quality, 1997 (E)
14 Irrigation technology transfer in support of food security, 1997 (E)
15 Irrigation in the countries of the former Soviet Union in figures, 1997 (E) (also published as RAP Publication 1997/22)
16 Télédétection et ressources en eau/Remote sensing and water resources, 1997 (F/E)
17 Institutional and technical options in the development and management of small-scale irrigation, 1998 (E)
18 Irrigation in Asia in figures, 1999 (E)
19 Modern water control and management practices in irrigation – Impact on performance, 1999 (E)
20 El riego en América Latina y el Caribe en cifras/Irrigation in Latin America and the Caribbean in figures, 2000 (S/E)
21 Water quality management and control of water pollution, 2000 (E)
22 Deficit irrigation practices, 2002 (E)
23 Review of world water resources by country, 2003 (E)
24 Rethinking the approach to groundwater and food security, 2003 (E)
25 Groundwater management: the search for practical approaches, 2003 (E)
26 Capacity development in irrigation and drainage. Issues, challenges and the way ahead, 2004 (E)
27 Economic valuation of water resources: from the sectoral to a functional perspective of natural resources management, 2004 (E)
28 Water charging in irrigated agriculture – An analysis of international experience, 2004 (E) efforts and results, 2007 (E)
29 Irrigation in Africa in figures – AQUASTAT survey – 2005, 2005 (E/F)
30 Stakeholder-oriented valuation to support water resources management processes – Confronting concepts with local practice, 2006 (E)
31 Demand for products of irrigated agriculture in sub-Saharan Africa, 2006 (E)
32 Irrigation management transfer – Worldwide, 2008 (E/S)
33 Scoping agriculture–wetland interactions – Towards a sustainable multiple-response strategy, 2008 (E)
34 Irrigation in the Middle East region in figures – AQUASTAT Survey – 2008, 2009 (Ar/E)
35 The Wealth of Waste: The economics of wastewater use in agriculture, 2010 (E)
36 Climate change, water and food security (E)
37 Irrigation in Southern and Eastern Asia in figures – AQUASTAT Survey – 2011 (E)
38 Coping with water scarcity - an action framework for agriculture and food security – 2012 (E)

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C	– Chinese	*	Out of print
E	– English	**	In preparation
F	– French		
P	– Portuguese		
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Coping with water scarcity

An action framework for agriculture and food security

In the 20th Century, water use has increased at more than twice the rate of population growth, to the point that in many regions overall demand for water can no longer be satisfied. Agriculture uses 70 percent of global freshwater withdrawals and is probably the sector where water scarcity is most critical. Under the joint pressure of population growth and changes in dietary habits, food consumption is increasing in most regions of the world, and it is expected that by 2050 an additional 60 percent of food will be needed to satisfy global demand.

Future policy decisions will increasingly need to reflect the tight linkage between water and food security, and be based on a clear understanding of opportunities and trade-offs in managing water for agricultural production. In order to guide its action in support of its member countries, FAO has recently embarked on a long-term programme on the theme "Coping with water scarcity – the role of agriculture". Based on an expert consultation, a conceptual framework has been developed to help address the question of food security under conditions of water scarcity. This report presents the conceptual framework, reviews a series of policy and technical options, and establishes a set of principles that should serve as a basis for the development of effective food security policies in response to growing water scarcity.

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