Summary

Water for food Water for life

A Comprehensive Assessment of Water Management in Agriculture

Edited by David Molden
for Comprehensive assessment of water management in agriculture

International Water Management Institute

EARTHSCAN

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Preface

The Comprehensive Assessment of Water Management in Agriculture is a critical evaluation of the benefits, costs, and impacts of the past 50 years of water development, the water management challenges communities face today, and the solutions people have developed around the world. It is a multi-institute process aimed at assessing the current state of knowledge and stimulating ideas on how to manage water resources to meet the growing needs for agricultural products, to help reduce poverty and food insecurity, and to contribute to environmental sustainability. The findings will enable better investment and management decisions in water and agriculture in the near future by considering their impact over the next 50 years.

The assessment was produced by a broad partnership of practitioners, researchers, and policymakers using an assessment process that engaged networks of partners to produce and synthesize knowledge and elaborate innovative methods and responses. An assessment, as distinct from a review, is undertaken for decisionmakers rather than scientists, is driven by a specific problem rather than more general scientific curiosity, requires a clear judgment as well as objective analysis, and deals with a range of uncertainty without being exhaustive.

The target audience of this assessment are the people who make the investment and management decisions in water management for agriculture—agricultural producers, water managers, investors, policymakers, and civil society. In addition, the assessment should inform the general public about these important issues, so that we can all help to make better decisions through our political processes.

The scope of this assessment is water management in agriculture, including fisheries and livestock, and the full spectrum of crop production from soil tillage through supplemental irrigation and water harvesting to full irrigation in a sustainable environment context. The assessment was originally framed by 10 questions, later expanded as interest grew (see box), and includes the overarching question: how can water in agriculture be developed and managed to help end poverty and hunger, ensure environmentally sustainable practices, and find the right balance between food and environmental security?

The Comprehensive Assessment places water management in agriculture in a social, ecological, and political context and assesses the dominant drivers of change. It explicitly addresses multiple use, feedbacks, and dynamic interactions between water for production systems, livelihood support, and the environment. It analyzes past and current water development efforts from the perspective of costs, benefits, and impacts, considering society (economic and rural development, increased food security, agricultural development, health, and poverty) and the environment (conservation and degradation of ecosystems and agriculture).

The Comprehensive Assessment covers major ground identified as important but not given thorough coverage in related assessments. The Millennium Ecosystem Assessment identified agriculture as a key driver of ecosystem change and at a global scale addressed the reasons for this and the responses available (MEA 2005). The World Water Assessment Programme considers all aspects of water and touches on water for agriculture in its report, but does not go into detailed analysis (UN–Water 2006). The ongoing International Assessment of Agricultural Science and Technology for Development (IAASTD) lists water as a key issue and draws on the results of the Comprehensive Assessment.

The Comprehensive Assessment used a participatory, open assessment process (Watson and Gitay 2004) that

- Provided a critical and objective evaluation of information for guiding decisions on a complex public issue.
- Engaged stakeholders early in the process and in building consensus or debating contentious issues.

Initial framing questions of the Comprehensive Assessment

These 10 questions were defined in 2001 by the Steering Committee of the Comprehensive Assessment:

1. What are the options and their consequences for improving water productivity in agriculture?
2. What have been the benefits, costs, and impacts of irrigated agricultural development, and what conditions those impacts?
3. What are the consequences of land and water degradation on water productivity and on the multiple users of water in catchments?
4. What are the extent and significance of use of low-quality water in agriculture (saline and wastewater), and what are the options for its use?
5. What are the options for better management of rainwater to support rural livelihoods, food production, and land rehabilitation in water-scarce areas?
6. What are the options and consequences for using groundwater?
7. How can water be managed to sustain and enhance capture fisheries and aquaculture systems?
8. What are the options for integrated water resources management in basins and catchments?
9. What policy and institutional frameworks are appropriate under various conditions for managing water to meet the goals of food and environmental security?
10. How much water will be needed for agriculture, given the need to meet food security and environmental sustainability goals?

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- Provided technically accurate, evidence-based analysis, summation, and synthesis that reduced complexity but added value to existing information.
- Was conducted by a large and diverse team of experts (scientists, practitioners, policymakers) to incorporate relevant geographic and disciplinary representation.
- Summarized its findings with simple and understandable messages for the target audience through clear answers to their questions, taking into account the multidisciplinary and multistakeholder involvement.
- Included external reviews with demonstrated response to the reviews to further strengthen objectivity, representation, and wide ownership.

To realize an informed, consultative, and inclusive assessment, scientists, policymakers, practitioners, and stakeholders were invited to participate. Through dialogue, debate, and other exchange, pertinent questions were identified and discussed. Background assessment research was conducted in a separate phase and is documented in a book series and reports (see www.iwmi.cgiar.org/assessment). Through collaboration with more than 700 individuals, numerous organizations, and networks, background material was developed and chapters were developed, reviewed, and improved.

Each chapter's writing team consisted of one to three coordinating lead authors, generally two to four lead authors, and five to ten contributing authors as well as a network of some 50 expert consultants. Each chapter went through two rounds of reviews with about 10 reviewers per round. A review editor verified that each review comment was addressed. The extensive review process represented another effort to engage civil society groups, researchers, and policymakers, among others. Cross-cutting issues of the Comprehensive Assessment were health, gender, and climate change. Groups of experts from these fields provided invaluable information and feedback to all of the chapters and commented on drafts of the texts. The process provided a mechanism for knowledge sharing, but also stimulated new thinking about water and food. The results thus provide not only an assessment of existing knowledge and experiences, but also new understanding of water management in agriculture.

The advantages of such an approach are numerous. It provides science-backed and policy-relevant findings, disseminates results throughout the process, and maintains high-quality science through the guidance of coordinating lead authors and the review process. Such an inclusive and collaborative procedure not only ensures greater scientific rigor, but also underscores authority and contributes to widespread ownership. The hope is that these efforts will result in significant changes in thinking and action on water management.

The Consultative Group on International Agricultural Research (CGIAR), the Secretariat of the Convention on Biological Diversity, the Food and Agriculture Organization of the United Nations, and the Ramsar Convention on Wetlands are co-sponsors of the assessment. While they have not formally endorsed the findings of the assessment, they have contributed to them and have expressed an interest in the results. Their role was to:

- Shape the assessment process by recommending key issues for assessment.
- Participate in developing the assessment.
- Transmit the results of the assessment to their constituents.

The Comprehensive Assessment (www.iwmi.cgiar.org/assessment) is organized through the CGIAR's Systemwide Initiative on Water Management (SWIM), which is convened by the International Water Management Institute, which initiated the process and provided a secretariat to facilitate the work. Involving food and environment communities together has been an important step in finding sustainable agricultural solutions.

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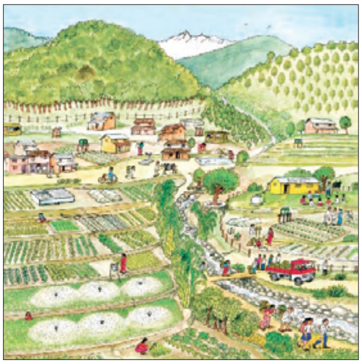


Agricultural water use—meeting the challenge of food security, poverty reduction, and environmental sustainability

Artist: Surendra Pradhan, Nepal

Summary for decisionmakers

Will there be enough water to grow enough food? Yes, if…

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?

The Comprehensive Assessment's answer: 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.

Why is the situation different now?

Fifty years ago the world had fewer than half as many people as it has today. They were not as wealthy. They consumed fewer calories, ate less meat, and thus required less water to produce their food. The pressure they inflicted on the environment was lower. They took from our rivers a third of the water that we take now.

Today the competition for scarce water resources in many places is intense. Many river basins do not have enough water to meet all the demands—or even enough for their rivers to reach the sea. Further appropriation of water for human use is not possible because limits have been reached and in many cases breached. Basins are effectively "closed," with no possibility of using more water. The lack of water is thus a constraint to producing food for hundreds of millions of people. Agriculture is central in meeting this challenge because the production of food and other agricultural products takes 70% of the freshwater withdrawals from rivers and groundwater.

Greater competition raises questions: Who will get the water, and how will allocations be decided? Conflict will grow between pastoralists and herders, between farms and cities, between those upstream and those downstream.

Not all contenders are human. Water used for agriculture is simply not available for wetlands, streams, deltas, and plants and animals. And as aquatic and terrestrial ecosystems are damaged, ecosystems change. Ecosystem services are threatened by the way we grow food. The climate is changing, affecting every facet of societies, ecosystems, and economies.

> Only if we act to improve water use in agriculture will we meet the acute freshwater challenges facing humankind over the coming 50 years

The trendlines shout out that we are not doing the right things. Inequity in the benefits of water use will grow between haves and have-nots to the detriment of food production. The pollution and depletion of rivers and groundwater will continue. Enough food grown at the aggregate global level does not mean enough food for everyone.

The Comprehensive Assessment of Water Management in Agriculture pulls together five years of work by more than 700 scientists and practitioners from around the world. Their strong and urgent message: problems will intensify unless they are addressed—and now.

Where is there hope? Increasing the productivity of land and water

The hope lies in closing the gap in agricultural productivity in many parts of the world—often today no greater than that on the fields of the Roman Empire—and in realizing the unexplored potential that lies in better water management along with nonmiraculous changes in policy and production techniques. The world has enough freshwater to produce food for all its people over the next half century. But world leaders must take action now—before the opportunities to do so are lost.

Some good news: 75% of the additional food we need over the next decades could be met by bringing the production levels of the world's low-yield farmers up to 80% of what high-yield farmers get from comparable land. Better water management plays a key role in bridging that gap.

More good news: the greatest potential increases in yields are in rainfed areas, where many of the world's poorest rural people live and where managing water is the key to such increases. Only if leaders decide to do so will better water and land management in these areas reduce poverty and increase productivity.

Even more good news: while there will probably be some need to expand the amount of land we irrigate to feed 8–9 billion people, and while we will have to deal with the associated adverse environmental consequences, with determined and focused change there is real scope to improve production on many existing irrigated lands. Doing so would lessen the need for more water in these areas and for even greater expansion of irrigated land. In South Asia—where more than half the crop area is irrigated and productivity is low—with determined policy change and robust institutions almost all additional food demand could be met by improving water productivity in already irrigated crop areas. In rural Sub-Saharan Africa comprehensive water management policies and sound institutions would spur economic growth for the benefit of all. And despite the bad news about groundwater depletion, there is still potential in many areas for highly productive pro-poor groundwater use, for example, the lower Gangetic plains and parts of Sub-Saharan Africa.

What changes are needed?

Such gains, although far from impossible, require big changes in the policy agenda for water management. That agenda must be grounded in the reality that ensuring food security and protecting ecosystems are vital to human survival and must be achieved in harmony. Water systems must be built for many purposes and managed to provide a wide range of ecosystem services. And there are opportunities—in rainfed, irrigated, livestock, and fisheries systems—for preserving, even restoring, healthy ecosystems.

Different strategies are required for different situations. Sub-Saharan Africa requires investments in infrastructure, considering the range of options available. Where infrastructure is already heavily developed, as in much of Asia, a focus on improving productivity, reallocating supplies, and rehabilitating ecosystems is required. In all cases, supporting institutions, adapted to changing needs, are essential.

There are also different pathways out of poverty. In some settings low-cost technologies can be viewed as a stepping stone—they are simple and can be rapidly implemented, reaping quick gains in food security and income for many people. And with favorable institutional and market conditions, other options will arise, such as larger scale irrigation or other income-generating and employment opportunities. But the first step is important.

Thinking differently about water is essential for achieving our triple goal of ensuring food security, reducing poverty, and conserving ecosystems.

What policy actions are needed?

Start with eight:

- *Policy action 1. Change the way we think about water and agriculture.* Thinking differently about water is essential for achieving our triple goal of ensuring food security, reducing poverty, and conserving ecosystems. Instead of a narrow focus on rivers and groundwater, view rain as the ultimate source of water that can be managed. Instead of blueprint designs, craft institutions while recognizing the politically contentious nature of the reform process. And instead of isolating agriculture as a production system, view it as an integrated multiple-use system and as an agroecosystem, providing services and interacting with other ecosytsems.
- *Policy action 2. Fight poverty by improving access to agricultural water and its use.* Target livelihood gains of smallholder farmers by securing water access through water rights and investments in water storage and delivery infrastructure where needed, improving value obtained by water use through pro-poor technologies, and investing in roads and markets. Multiple-use systems—operated for domestic use, crop production, aquaculture, agroforestry, and livestock—can improve water productivity and reduce poverty.
- *Policy action 3. Manage agriculture to enhance ecosystem services.* Good agricultural practice can enhance other ecosystem services. In agroecosystems there is scope to promote services beyond the production of food, fiber, and animal protein. Agricultural production does not have to be at the expense of other services that water provides in rivers and wetlands. But because of increased water and land use, and intensification, some ecosystem change is unavoidable, and difficult choices are necessary.

- *Policy action 4. Increase the productivity of water.* Gaining more yield and value from less water can reduce future demand for water, limiting environmental degradation and easing competition for water. A 35% increase in water productivity could reduce additional crop water consumption from 80% to 20%. More food can be produced per unit of water in all types of farming systems, with livestock systems deserving attention. But this optimism should be met with caution because in areas of high productivity only small gains are possible. Larger potential exists in getting more value per unit of water, especially through integrated systems and higher value production systems and through reductions in social and environmental costs. With careful targeting, the poor can benefit from water productivity gains in crop, fishery, livestock, and mixed systems.

> A wider policy and investment arena needs to be opened by breaking down the divides between rainfed and irrigated agriculture and by better linking fishery and livestock practices to water management

- *Policy action 5. Upgrade rainfed systems—a little water can go a long way.* Rainfed agriculture is upgraded by improving soil moisture conservation and, where feasible, providing supplemental irrigation. These techniques hold underexploited potential for quickly lifting the greatest number of people out of poverty and for increasing water productivity, especially in Sub-Saharan Africa and parts of Asia. Mixed crop and livestock systems hold good potential, with the increased demand for livestock products and the scope for improving the productivity of these systems.
- *Policy action 6. Adapt yesterday's irrigation to tomorrow's needs.* The era of rapid expansion of irrigated agriculture is over. A major new task is adapting yesterday's irrigation systems to tomorrow's needs. Modernization, a mix of technological and managerial upgrading to improve responsiveness to stakeholder needs, will enable more productive and sustainable irrigation. As part of the package irrigation needs to be better integrated with agricultural production systems to support higher value agriculture and to integrate livestock, fisheries, and forest management.
- *Policy action 7. Reform the reform process—targeting state institutions.* Following a realistic process to suit local needs, a major policy shift is required for water management investments important to irrigated and rainfed agriculture. A wider policy and investment arena needs to be opened by breaking down the divides between rainfed and irrigated agriculture and by better linking fishery and livestock practices to water management. Reform cannot follow a blueprint. It takes time. It is specific to the local institutional and political context. And it requires negotiation and coalition building. Civil society and the private sector are important actors. But the state is often the critical driver, though state water institutions are often the most in need of reform.
- *Policy action 8. Deal with tradeoffs and make difficult choices.* Because people do not adapt quickly to changing environments, bold steps are needed to engage with stakeholders. Informed multistakeholder negotiations are essential to make decisions about the use and allocation of water. Reconciling competing demands on water requires transparent sharing of information. Other users—fishers, smallholders without official title, and those dependent on ecosystem services—must develop a strong collective voice.

Divergent views—divergent understanding

Views diverge sharply on the competing choices for water for food and for ecosystems. Some emphasize developing more water through large infrastructure to relieve scarcity, fuel economic growth, protect vulnerable people, and relieve pressure on the environment. Projects to transfer water from water-abundant to water-scarce basins follow this approach. At the other end of the spectrum are calls for a halt to agricultural and hydraulic infrastructure expansion—and for practices that restore ecosystems.

A major reason for the diverging views is divergent understanding of some basic premises. How much water is used in agriculture? How much irrigation is there? What is the contribution of groundwater? And what is the present use and future potential of rainfed agriculture? Different people place different values on water use. There is also a lack of knowledge and awareness of past impacts and the current situation of water use. By bringing together a diverse group of people with different perspectives, this assessment has made strides in finding common ground.

A major reason for the diverging views on competing choices for water for food and water for ecosystems is divergent understanding of some basic premises

How much water is used for agriculture?

To produce enough food to satisfy a person's daily dietary needs takes about 3,000 liters of water converted from liquid to vapor—about 1 liter per calorie. Only about 2–5 liters of water are required for drinking. In the future more people will require more water for food, fiber, industrial crops, livestock, and fish. But the amount of water per person can be reduced by changing what people consume and how they use water to produce food.

Imagine a canal 10 meters deep, 100 meters wide, and 7.1 million kilometers long—long enough to encircle the globe 180 times. That is the amount of water it takes each year to produce food for today's 6.5 billion people. Add 2–3 billion people and accommodate their changing diets from cereals to more meat and vegetables and that could add another 5 million kilometers to the channel of water needed to feed the world's people.

About 80% of agricultural evapotranspiration—when crops turn water into vapor (box 1)—comes directly from rain, and about 20% from irrigation (map 1). Arid areas like the Middle East, Central Asia, and the western United States tend to rely on irrigation. There has also been large-scale irrigation development in South and East Asia, less in Latin America, and very little in Sub-Saharan Africa.

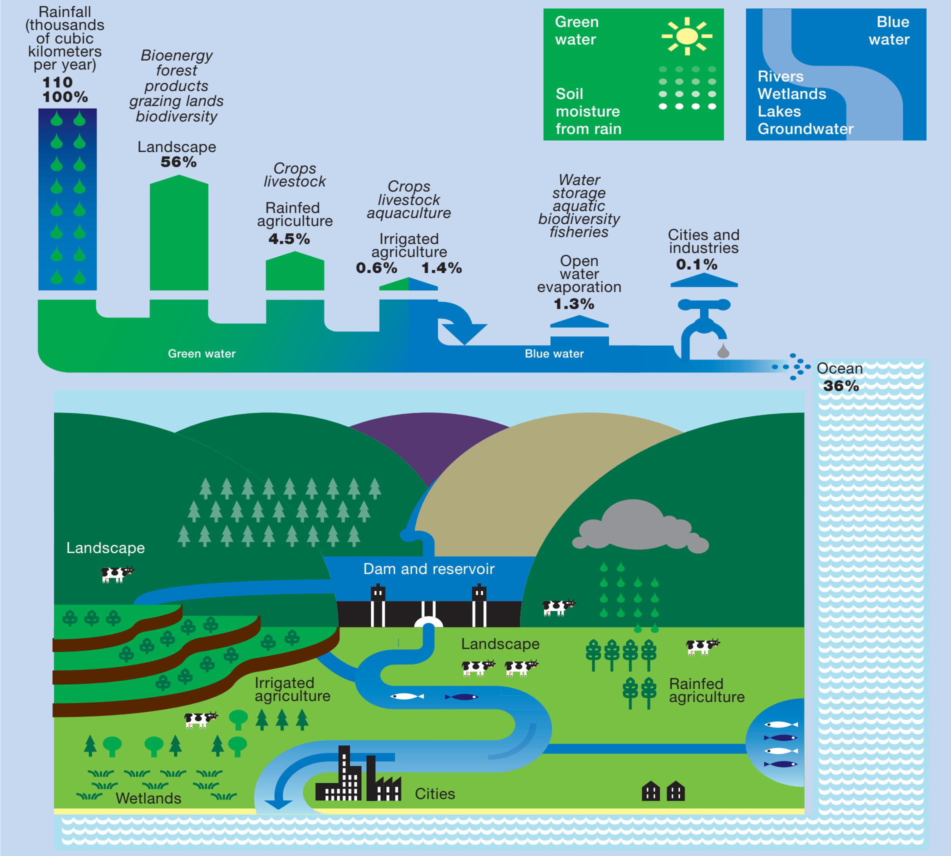
Withdrawals of water by agriculture (70%), industry (20%), and municipalities (10%)

Consider how we use water from rivers, lakes, and groundwater—blue water. Total global freshwater withdrawals are estimated at 3,800 cubic kilometers, with 2,700 cubic kilometers (or 70%) for irrigation, with huge variations across and within countries. Industrial and domestic use is growing relative to that for agriculture. And water for energy generation—hydropower and thermo cooling—is growing rapidly. Not all water withdrawn is "lost." Much is available for reuse in river basins, but often its quality is degraded.

Water, the blood of the biosphere, connects ecosystems across the landscape. When agricultural activities change the quality, quantity, and timing of water flows, box **1** | **Water use in rainfed and irrigated agriculture**

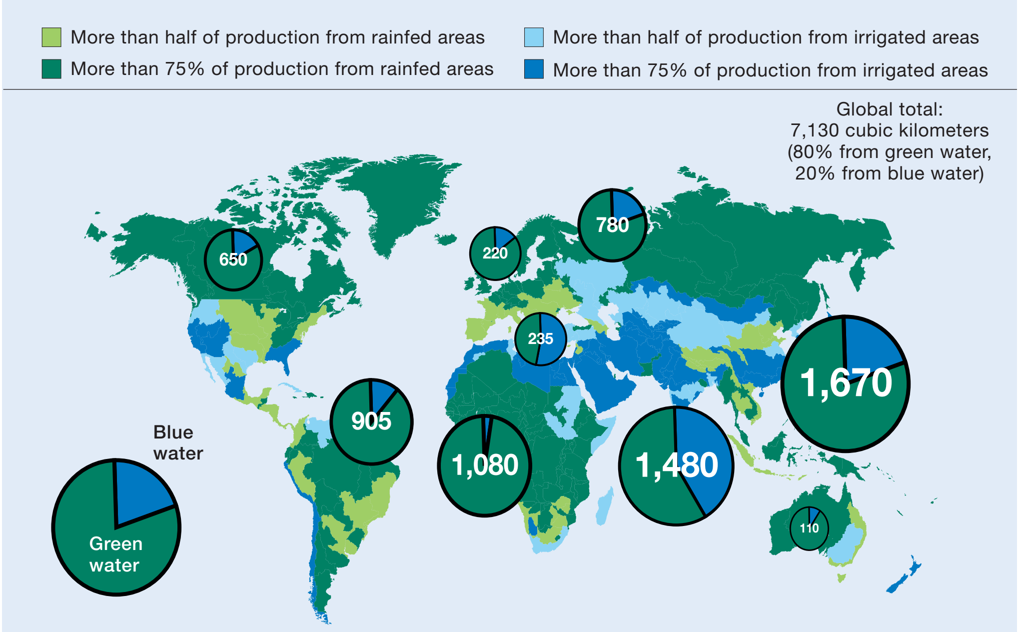
The illustration shows how water is used globally and the services each use provides. The main source of water is rain falling on the earth's land surfaces (110,000 cubic kilometers). The arrows express the magnitude of water use, as a percentage of total rainfall, and the services provided. So, for example, 56% of green water is evapotranspired by various landscape uses that support bioenergy, forest products, livestock grazing lands, and biodiversity, and 4.5% is evapotranspired by rainfed agriculture supporting crops and livestock. Globally, about 39% of rain (43,500 cubic kilometers) contributes to blue water sources, important for supporting biodiversity, fisheries, and aquatic ecosystems. Blue water withdrawals are about 9% of total blue water sources (3,800 cubic kilometers), with 70% of withdrawals going to irrigation (2,700 cubic kilometers). Total evapotranspiration by irrigated agriculture is about 2,200 cubic kilometers (2% of rain), of which 650 cubic kilometers are directly from rain (green water) and the remainder from irrigations water (blue water). Cities and industries withdraw 1,200 cubic kilometers but return more than 90% to blue water, often with degraded quality. The remainder flows to the sea, where it supports coastal ecosystems. The variation across basins is huge. In some cases people withdraw and deplete so much water that little remains to flow to the sea.

Global water use



Source: Calculations for the Comprehensive Assessment of Water Management in Agriculture based on data from T. Oki and S. Kanae, 2006, "Global Hydrological Cycles and World Water Resources," *Science* 313 (5790): 1068–72; UNESCO–UN World Water Assessment Programme, 2006, *Water: A Shared Responsiblity,* The United Nations World Water Development Report 2, New York, UNESCO and Berghahn Books.

map **1** **Regional variation in evapotranspiration in rainfed and irrigated agriculture**



Note: Production refers to gross value of production. The pie charts show total crop water evapotranspiration in cubic kilometers by region.

Source: International Water Management Institute analysis done for the Comprehensive Assessment for Water Management in Agriculture using the Watersim model; chapter 2.

this can change connected systems' capacity to produce ecosystem services other than food. Some changes to ecosystems are unavoidable simply because of the amount of water needed to produce food. But much ecosystem change is avoidable, if water is managed well.

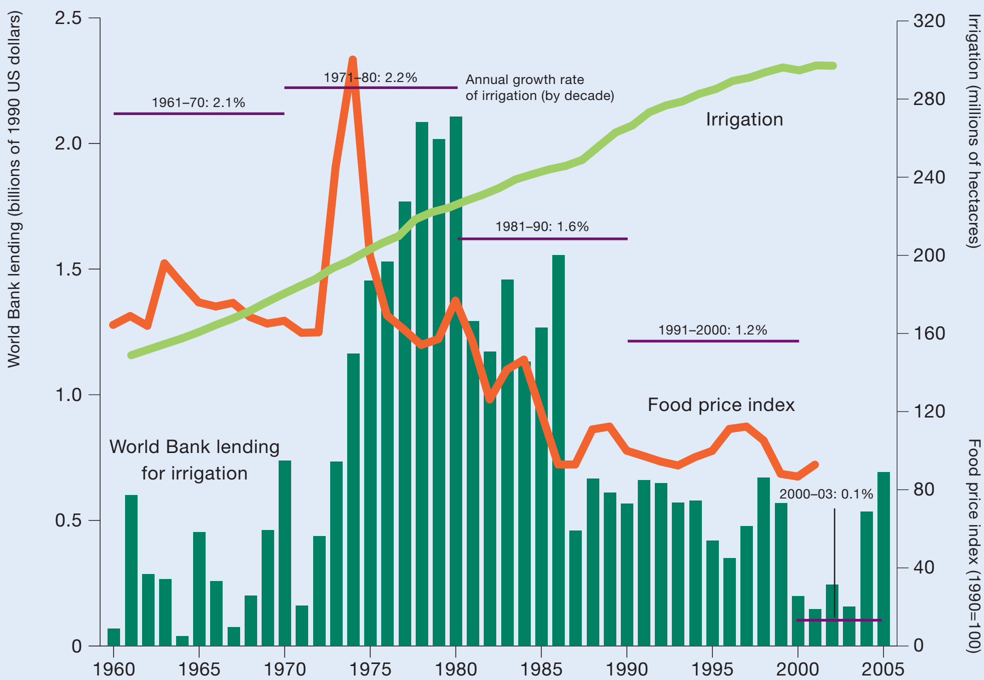
Water for food—water for life

The last 50 years have seen remarkable developments in water resources and in agriculture. Massive developments in hydraulic infrastructure have put water at the service of people. While the world population grew from 2.5 billion in 1950 to 6.5 billion today, the irrigated area doubled and water withdrawals tripled.

Agricultural productivity grew thanks to new crop varieties and fertilizers, fueled by additional irrigation water. World food production outstripped population growth. Global food prices declined markedly (figure 1). And the greater use of water for irrigated agriculture benefited farmers and poor people—propelling economies, improving livelihoods, and fighting hunger.

But much unfinished business remains. In 2003, 850 million people in the world were food insecure, 60% of them living in South Asia and Sub-Saharan Africa, and 70%

figure **1** | **Irrigation expanding, food prices falling**



Source: Based on World Bank and Food and Agriculture Organization data; chapter 9.

of the poor live in rural areas. In Sub-Saharan Africa the number of food-insecure people rose from 125 million in 1980 to 200 million in 2000.

The last 50 years have also witnessed unprecedented changes in ecosystems, with many negative consequences. The Millennium Ecosystem Assessment pointed out that growth in agriculture has been responsible for much of this change. Agricultural practices have contributed primarily to the loss of regulating ecosystem services—such as pollination, biological pest control, flood retention capacity, and changes in microclimate regulation—and to the loss of biodiversity and habitats. Our message: better water management can mitigate many of the negative consequences.

Promising trends

- Per capita consumption of food and total consumption of fruits, vegetables, and livestock products are steadily rising, leading to better nutrition for many and a decrease in the percentage of undernourished people. The average global per capita daily food supply increased from 2,400 kilocalories (kcal) in 1970 to 2,800 kcal in 2000, so enough food was produced globally to feed a growing population.

- Land and water productivity are also rising steadily—with average grain yields rising from 1.4 metric tons per hectare to 2.7 metric tons over the past four decades.
- New investments in irrigation and agricultural water management have the potential to spur economic growth within agriculture and other sectors. And using lessons from the past, investments can incur fewer social and environmental costs. In some areas environmental degradation has been reduced because of better natural resources management.
- An increase in global trade in food products and in consequent flows of virtual water (the water embodied in food exports) offers prospects for better national food security and the possibility of relieving water stress.

Growth in agriculture has been responsible for much of the loss of biodiversity and habitats and of regulating ecosystem services. Better water management can mitigate many of the negative consequences.

Disturbing trends

- The number of people malnourished remains about 850 million.
- The average daily per capita food supply in South Asia (2,400 kcal) and Sub-Saharan Africa (2,200 kcal), while slowly rising, remains below the world average of 2,800 kcal in 2000 and far below the excessively high level in industrial countries (3,450 kcal). There are large losses of food between what is supplied and what is consumed by people—on the order of a third—an indirect waste of water.
- Pollution is increasing, and rivers are drying up because of greater agricultural production and water consumption. Freshwater fisheries, important for the livelihoods of rural poor, have been damaged or are threatened. Land and water resources are being degraded through erosion, pollution, salinization, nutrient depletion, and the intrusion of seawater.
- Pastoralists, many relying on livestock as their savings, are putting the world's grazing lands under great pressure.
- In several river basins water is poorly managed, and allocations to users (including the environment) are overcommitted, so there is not enough water to meet all demands.
- Groundwater levels are declining rapidly in densely populated areas of North Africa, North China, India, and Mexico because of overexploitation.
- Water management institutions have been slow to build or change capacity and adapt to new issues and conditions.

Double-edged trends

- Increasing water withdrawals and water depletion for irrigation in developing countries have been good for economic growth and poverty alleviation—but often bad for the environment.
- Agricultural subsidies can be beneficial if applied judiciously as a management tool to support income generation by the rural poor and to protect the environment. If not so applied, they distort water and agricultural practices.

- The growing demand of cities and industries for water offers possibilities for employment and income. But it also shifts water out of agriculture, puts extra strain on rural communities, and pollutes water.
- Consumption of fish and meat is rising, increasing the reliance on aquaculture and industrial livestock production, with benefits for income and well-being but with more pressure on water resources and the environment.

> A growing population is a major factor behind today's water scarcity, but the main reasons for water problems are lack of commitment and targeted investment, insufficient human capacity, ineffective institutions, and poor governance

And emerging forces

- The climate is changing, affecting temperatures and precipitation patterns. Tropical areas with intense poverty, such as a large part of Sub-Saharan Africa, will be most adversely affected. Irrigators dependent on snow melt are even more vulnerable to changes in river flows.
- Globalization continues over the long run, providing new opportunities for commercial and high-value agriculture but presenting new challenges for rural development.
- Urbanization increases demand for water, generates more wastewater, and alters patterns of demand for agricultural products.
- Higher energy prices increase the costs of pumping water, applying fertilizers, and transporting products. Greater reliance on bioenergy will affect the production and prices of food crops and increase the amount of water used by agriculture.
- Perceptions and thinking about water are changing, with water professionals and policymakers realizing (again) the need to improve the use not only of blue water (in lakes, rivers, and aquifers) but also that of green water (soil moisture).
- More attention is being given to ecosystem and other integrated approaches and to understanding how forces outside water for agriculture influence both water and agriculture.

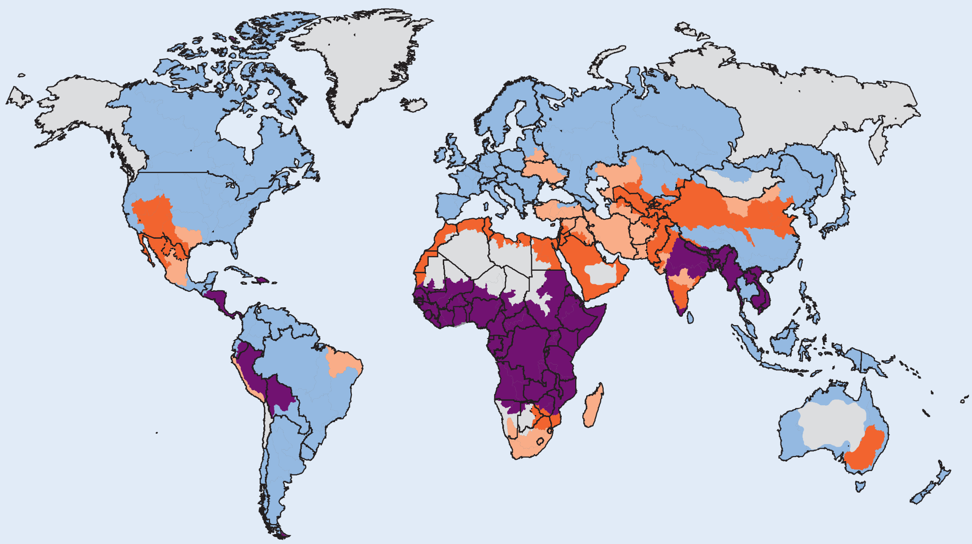
Water scarcity—water management

Without better water management in agriculture the Millennium Development Goals for poverty, hunger, and a sustainable environment cannot be met. Access to water is difficult for millions of poor women and men for reasons that go beyond the physical resource base. In some places water is abundant, but getting it to people is difficult because of lack of infrastructure and because of restricted access as a result of political and sociocultural issues. In other places, people's demands go beyond what the natural resource base can handle, and not everyone is assured access to water.

Water scarcity, defined in terms of access to water, is a critical constraint to agriculture in many areas of the world. A fifth of the world's people, more than 1.2 billion, live in areas of physical water scarcity, lacking enough water for everyone's demands. About 1.6 billion people live in water-scarce basins, where human capacity or financial resources are likely to be insufficient to develop adequate water resources (map 2). Behind today's water scarcity lie factors likely to multiply and gain in complexity over the coming years. A growing population is a major factor, but the main reasons for water problems lie elsewhere—lack of commitment to water and poverty, inadequate and inadequately targeted investment, insufficient human capacity, ineffective institutions, and poor governance.

map **2** | **Areas of physical and economic water scarcity**

- Little or no water scarcity
- Physical water scarcity
- Approaching physical water scarcity
- Economic water scarcity
- Not estimated



Definitions and indicators

- *Little or no water scarcity.* Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- *Physical water scarcity (water resources development is approaching or has exceeded sustainable limits).* More than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.
- *Approaching physical water scarcity.* More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- *Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands).* Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

Source: International Water Management Institute analysis done for the Comprehensive Assessment of Water Management in Agriculture using the Watersim model; chapter 2.

Economic scarcity

Economic scarcity is caused by a lack of investment in water or a lack of human capacity to satisfy the demand for water. Much of the scarcity is due to how institutions function, favoring one group over another and not hearing the voices of various groups, especially women.

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. And even where infrastructure exists, the distribution of water may be inequitable. Much of Sub-Saharan Africa is characterized by economic scarcity, so further water development could do much to reduce poverty.

Physical scarcity

Physical scarcity occurs when there is not enough water to meet all demands, including environmental flows. Arid regions are most often associated with physical water scarcity, but water scarcity also appears where water is apparently abundant, when water resources are overcommitted to various users due to overdevelopment of hydraulic infrastructure, most often for irrigation. In such cases there simply is not enough water to meet both human demands and environmental flow needs. Symptoms of physical water scarcity are severe environmental degradation, declining groundwater, and water allocations that favor some groups over others.

> Climate change will affect all facets of society and the environment, with strong implications for water and agriculture now and in the future

New challenges beyond scarcity

Energy affects water management now and will do so even more in the future. Energy prices are rising, pushing up the costs of pumping water, manufacturing fertilizers, and transporting products. This will have implications for access to water and irrigation. Increased hydropower will mean increased competition for water with agriculture.

Climate change policy is increasingly supporting greater reliance on bioenergy as an alternative to fossil fuel–based energy. But this is not consistently coupled with the water discussion. The Comprehensive Assessment estimates that with heavy reliance on bioenergy the amount of agricultural evapotranspiration in 2050 to support increased bioenergy use will be about what is depleted for all of agriculture today. Reliance on bioenergy will further intensify competition for water and land, so awareness of the "double-edged" nature of bioenergy needs to be raised.

Urbanization and the global market will dictate the choices of farmers around the world. Changes in the global market and the spread of globalization will determine the profitability of agriculture. Where suitable infrastructure and national policies are in place, a variety of shifting niche markets will emerge, creating opportunities for innovative entrepreneurial farmers. In some countries the contribution of farming to the national economy will shrink, with implications for smallholders and subsistence farmers who rely on extension, technology, and regional markets. The demographics of farming change with urbanization. Many women and older people will be left in rural areas to look after farms Yet agricultural development remains the single most promising engine of growth in the majority of Sub-Saharan countries. To ensure the sustainability of the agriculture sector in many of these countries, investments in technology and capacity building need to go hand in hand with policies that make farming profitable.

Climate change will affect all facets of society and the environment, directly and indirectly, with strong implications for water and agriculture now and in the future. The climate is changing at an alarming rate, causing temperature rise, shifting patterns of precipitation, and more extreme events. Agriculture in the subtropics—where most poor countries are situated—will be affected most. The future impacts of climate change need to be incorporated into project planning, with behavior, infrastructure, and investments all requiring adjusting to adapt to a changing set of climate parameters. Water storage and control investments will be important rural development strategies to respond to climate change. The impacts of policies and laws set up to reduce greenhouse gas emissions or adjust to a changing climate also need to be taken into account.

Future demand for food—and for water

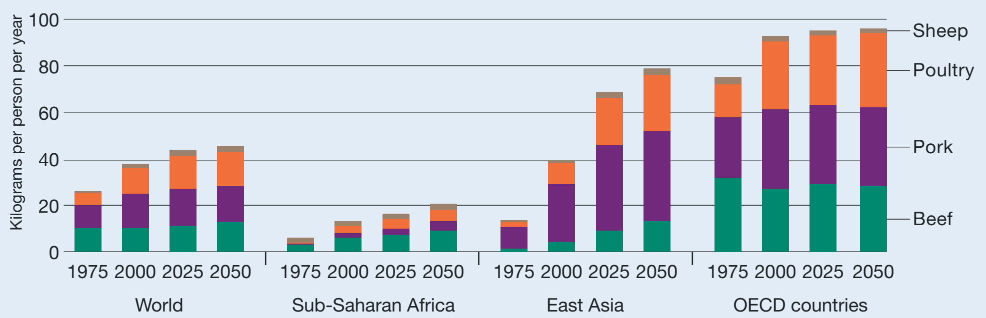
As population grows, so will demand for food and water.

How much more food?

Food and feed crop demand will nearly double in the coming 50 years. The two main factors driving how much more food we will need are population growth and dietary change. With rising incomes and continuing urbanization, food habits change toward more nutritious and more varied diets—not only toward increasing consumption of staple cereals but also to a shift in consumption patterns among cereal crops and away from cereals toward livestock and fish products and high-value crops (figures 2 and 3).

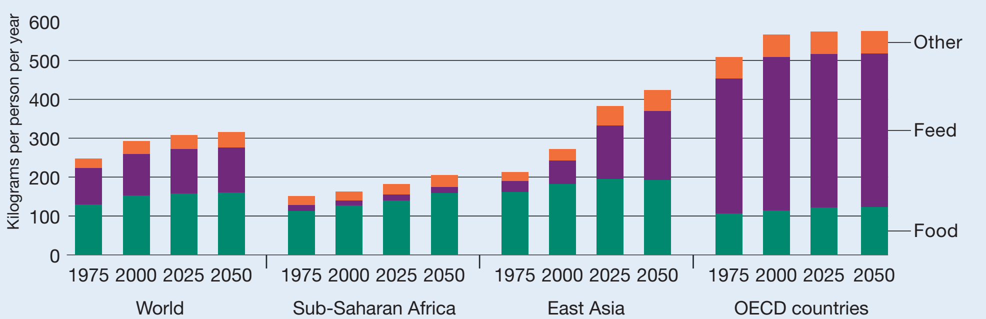
Per capita food supply in Organisation for Economic Co-operation and Development (OECD) countries will level off well above 2,800 kcal, which is usually taken as

figure **2** | **Meat consumption more than doubles in East Asia by 2050**



Source: for 1975 and 2000, FAOSTAT statistical database; for 2025 and 2050, International Water Management Institute analysis done for the Comprehensive Assessment of Water Management in Agriculture using the Watersim model; chapter 3.

figure **3** | **Feed demand drives future demand for grains**



Source: for 1975 and 2000, FAOSTAT statistical database; for 2025 and 2050, International Water Management Institute analysis done for the Comprehensive Assessment of Water Management in Agriculture using the Watersim model; chapter 3.

a threshold for national food security. People in low- and middle-income countries will substantially increase their calorie intake, but a significant gap between poor and rich countries will likely remain in the coming decades.

Producing meat, milk, sugar, oils, and vegetables typically requires more water than producing cereals—and a different style of water management. Increasing livestock production requires even more grain for feed, leading to a 25% increase in grains. Thus, diets are a significant factor in determining water demands. While feed-based meat production may be water costly, grazing systems behave quite differently. From a water perspective grazing is probably the best option for large land areas, but better grazing and watering practices are needed.

> Without further improvements in water productivity by 2050 the amount of water evaporated in crop production will almost double from today's amount

How much more water?

Without further improvements in water productivity or major shifts in production patterns, the amount of water consumed by evapotranspiration in agriculture will increase by 70%–90% by 2050. The total amount of water evaporated in crop production would amount to 12,000–13,500 cubic kilometers, almost doubling the 7,130 cubic kilometers of today. This corresponds to an average annual increase of 100–130 cubic kilometers, almost three times the volume of water supplied to Egypt through the High Aswan Dam every year.

On top of this is the amount of water needed to produce fiber and biomass for energy. Cotton demand is projected to grow by 1.5% annually, and demand for energy seems insatiable. By 2030 world energy demand will rise by 60%, two-thirds of the increase from developing countries, some from bioenergy.

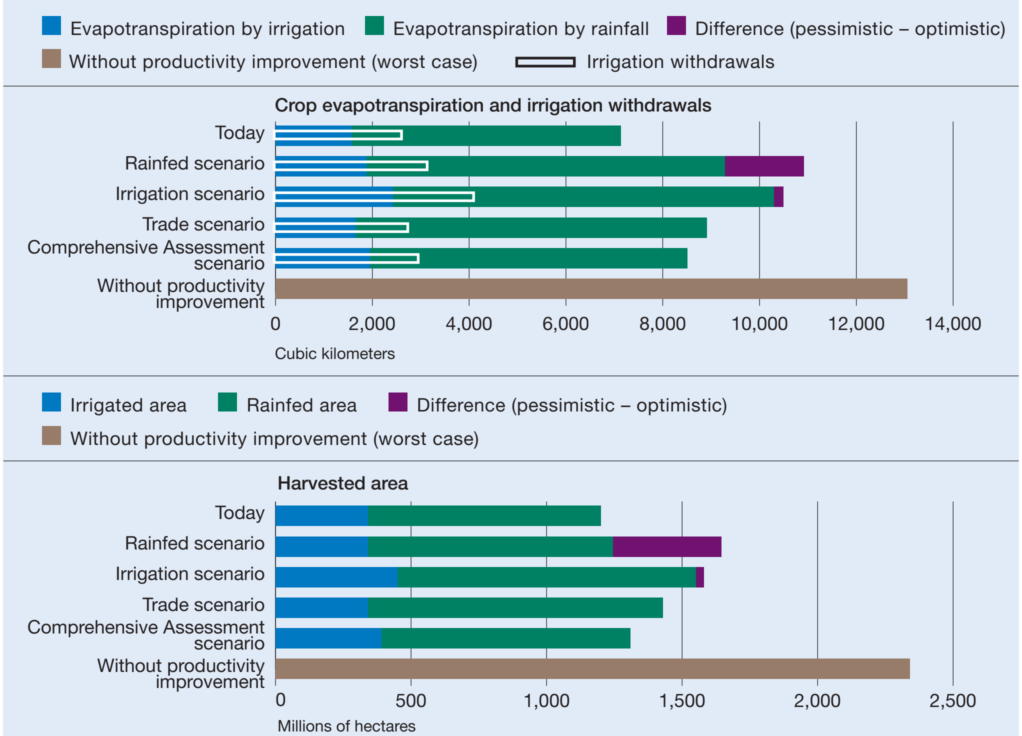
Fortunately, water productivity in agriculture has steadily increased in the past decades, in large part due to increases in crop yields, and will continue to do so. The pace of this increase can vary substantially according to the type of policies and investments put in place, with substantial variation in impacts on the environment and the livelihoods of agricultural populations. Key options are explored below, using a set of scenarios (figure 4).

How can we meet food and fiber demand with our land and water resources?

The world's available land and water resources can satisfy future food demands in several ways.

- Investing to increase production in rainfed agriculture (rainfed scenario).
  - Increasing productivity in rainfed areas through enhanced management of soil moisture and supplemental irrigation where small water storage is feasible.
  - Improving soil fertility management, including the reversal of land degradation.
  - Expanding cropped areas.
- Investing in irrigation (irrigation scenario).
  - Increasing annual irrigation water supplies by innovations in system management, developing new surface water storage facilities, and increasing groundwater withdrawals and the use of wastewater.
  - Increasing water productivity in irrigated areas and value per unit of water by integrating multiple uses—including livestock, fisheries, and domestic use—in irrigated systems.
- Conducting agricultural trade within and between countries (trade scenario).

figure 4 | Land and water use today and in the future under different scenarios



Note: The figure shows projected amounts of water and land requirements under different scenarios. The Comprehensive Assessment scenario combines elements of the other approaches (see chapter 3 for details). The purple segments of the bars show the difference between optimistic and pessimistic assumptions for the two rainfed and two irrigated scenarios. The brown bar shows the worst cases scenario of no improvement in productivity.

Source: International Water Management Institute analysis done for the Comprehensive Assessment for Water Management in Agriculture using the Watersim model; chapter 3.

- Reducing gross food demand by influencing diets, and reducing post-harvest losses, including industrial and household waste.

Each of these strategies will affect water use, the environment, and the poor—but in very different ways, depending on the local setting. The Comprehensive Assessment scenario combines elements of different approaches suited to each region.

Can upgrading rainfed agriculture meet future food demands?

Today, 55% of the gross value of our food is produced under rainfed conditions on nearly 72% of the world's harvested cropland. In the past, many countries focused their "water attention" and resources on irrigation development. The future food production that should come from rainfed or irrigated agriculture is the subject of intense debate, and the policy options have implications that go beyond national boundaries.

An important option is to upgrade rainfed agriculture through better water management practices. Better soil and land management practices can increase water productivity, adding a component of irrigation water through smaller scale interventions such as rainwater harvesting. Integrating livestock in a balanced way to increase the productivity of livestock water is important in rainfed areas.

At the global level the potential of rainfed agriculture is large enough to meet present and future food demand through increased productivity (see figure 4, rainfed scenario). An optimistic rainfed scenario assumes significant progress in upgrading rainfed systems while relying on minimal increases in irrigated production, by reaching 80% of the maximum obtainable yield. This leads to an average increase of yields from 2.7 metric tons per hectare in 2000 to 4.5 in 2050 (1% annual growth). With no expansion of irrigated area, the total cropped area would have to increase by only 7%, compared with 24% from 1961 to 2000, to keep pace with rising demand for agricultural commodities.

> At the global level the potential of rainfed agriculture is large enough to meet present and future food demand through increased productivity

But focusing only on rainfed areas carries considerable risks. If adoption rates of improved technologies are low and rainfed yield improvements do not materialize, the expansion in rainfed cropped area required to meet rising food demand would be around 53% by 2050 (figure 4). Globally, the land for this is available, but agriculture would then encroach on marginally suitable lands and add to environmental degradation, with more natural ecosystems converted to agriculture.

What can irrigated agriculture contribute?

Under optimistic assumptions about water productivity gains, three-quarters of the additional food demand can be met by improving water productivity on existing irrigated lands. In South Asia—where more than 50% of the cropped area is irrigated and productivity is low—additional food demand can be met by improving water productivity in irrigated agriculture rather than by expanding the area under production. But in parts of China and Egypt and in developed countries, yields and water productivity are already quite high, and the scope for further improvements is limited. In many rice-growing areas water savings during the wet season make little sense because they will not be easily available for other uses.

An alternative strategy is to continue expansion of irrigated land because it provides access to water to more people and can provide a more secure food future (see figure 4, irrigation scenario). Irrigation could contribute 55% of the total value of food supply by 2050. But that expansion would require 40% more withdrawals of water for agriculture, surely a threat to aquatic ecosystems and capture fisheries in many areas. In Sub-Saharan Africa there is very little irrigation, and expansion seems warranted. Doubling the irrigated area in Sub-Saharan Africa would increase irrigation's contribution to food supply from only 5% now to an optimistic 11% by 2050.

What is the potential of trade to release pressure on freshwater resources?

By importing agricultural commodities, a nation "saves" the amount of water it would have required to produce those commodities domestically. Egypt, a highly water-stressed country, imported 8 million metric tons of grain from the United States in 2000. To produce this amount of grain Egypt would have needed about 8.5 cubic kilometers of irrigation water (Egypt's annual supply from Lake Nasser is 55.6 cubic kilometers). Japan, a land-scarce country and the world's biggest grain importer, would require an additional 30 billion cubic meters of crop water consumption to grow the food it imports. Cereal trade has a moderating impact on the demand for irrigation water, because the major grain exporters—the United States, Canada, France, Australia, and Argentina—produce grain in highly productive rainfed conditions.

A strategic increase in international food trade could thus mitigate water scarcity and reduce environmental degradation (see figure 4, trade scenario). Instead of striving for food self-sufficiency, water-short countries would import food from water-abundant countries. But poor countries depend, to a large extent, on their national agriculture sector, and the purchasing power required to cover food needs from the world market is often low. Struggling with food security, these countries remain wary of depending on imports to satisfy basic food needs. A degree of food self-sufficiency is still an important policy goal. And despite emerging water problems, many countries view the development of water resources as a more secure option to achieving food supply goals and promoting income growth, particularly in poor rural communities. The implication is that under the present global and national geopolitical and economic situation, it is unlikely that food trade will solve water scarcity problems in the near term.

But even in an optimistic investment scenario, by 2050 the cropped area will increase by 9% and water withdrawals for agriculture will increase by 13%

Influencing what happens next

With the increases in world food demand inevitable, agriculture will require more land and water. Part of the increase in food production can be achieved by improving crop yields and increasing crop water productivity, through appropriate investments in both irrigated and rainfed agriculture (table 1) as in the Comprehensive Assessment scenario. But even in an optimistic investment scenario (see figure 4, Comprehensive Assessment scenario), by 2050 the cropped area will increase by 9% and water withdrawals for agriculture will increase by 13%, taking resources away from other ecosystems. One challenge is to manage this additional water in a way that minimizes the adverse impacts on—and where possible enhances—ecosystem services and aquatic food production, while providing the necessary gains in food production and poverty alleviation. Doing so will require a water-food-environment policy agenda suited to each country and region.

table **1** **Comprehensive Assessment scenario characteristics**

Region	Scope for improved productivity in rainfed areas	Scope for improved productivity in irrigated areas	Scope for irrigated area expansion
Sub-Saharan Africa	High	Some	High
Middle East and North Africa	Some	Some	Very limited
Central Asia and Eastern Europe	Some	Good	Some
South Asia	Good	High	Some
East Asia	Good	High	Some
Latin America	Good	Some	Some
OECD countries	Some	Some	Some

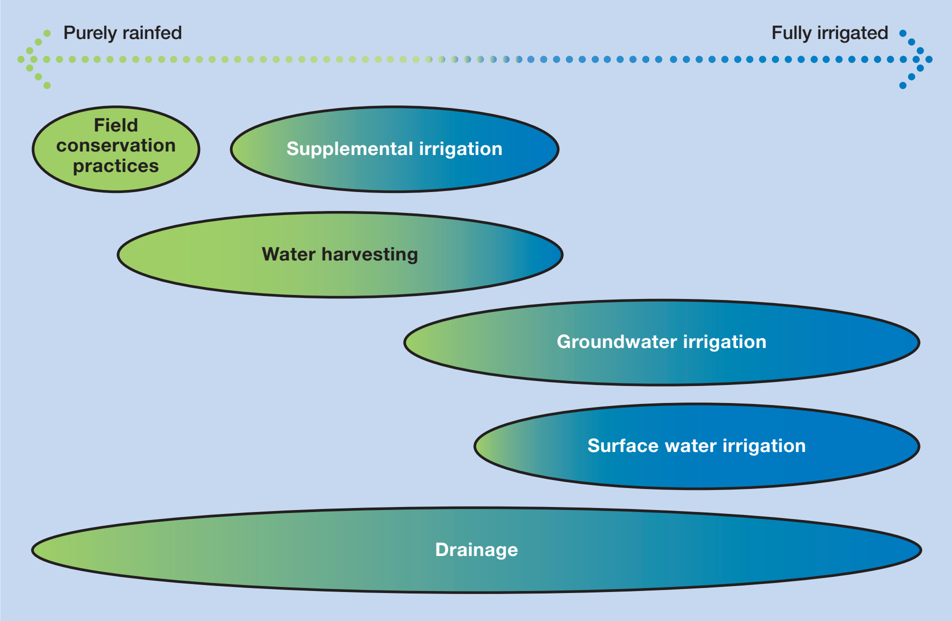
There is a need to invest in water. But the type of investment and how it is carried out make all the difference. The Comprehensive Assessment's view on investments is broad and considers a range of options (box 2). It includes investments in improving management, building effective institutions to meet changing demands, and increasing knowledge and human capacity. Despite good intentions it is difficult to make meaningful investments in crafting institutions and empowering people to make better choices about water. And it is often easier and politically more expedient to build large infrastructure without considering alternatives and the environmental and social costs. This must change.

A combination of investment, policy, and research approaches will clearly be needed, and each strategy will have risks and tradeoffs. Any strategy will require a concurrent policy shift. The global policy and economic environment will provide the overall framework for

box **2** | **The spectrum from rainfed to irrigated**

Managing water for agriculture includes a spectrum of options—from producing under fully irrigated to entirely rainfed conditions, to supporting livestock, forestry, and fisheries, and to interacting with important ecosystems. The continuum of water management practices starts with fields or grazing land entirely dependent on rainwater. On-farm conservation practices focus on storing water in the soil. Moving along the continuum, more surface water or groundwater is added to enhance crop production. This additional freshwater provides opportunities for multiple uses, including aquaculture and livestock within the production system.

Diverse options for agricultural water management along the spectrum



local agriculture, but local conditions will dictate the choices for future water investments in agriculture.

Change does not always require governments to spend huge sums of money. Many informed investment decisions can save money—a lot of money. And when the conditions are right, individuals will invest in water for their own welfare.

Policy action 1 Change the way we think about water and agriculture

Change does not always require governments to spend huge sums of money. Many informed investment decisions can save money

Today's water management challenges—and tomorrow's—differ greatly from those of recent decades. More water will be needed for agriculture to reduce hunger and feed a growing population. But the impacts on poverty and ecosystems will depend on the type of investments. Thinking differently about water is a requirement if we want to achieve our triple goal of ensuring food security, reducing poverty, and conserving ecosystem integrity.

Like the challenges, the investments required today differ greatly from those in the last half century. They will have to increase human and institutional capacity and improve management and infrastructure, integrating the needs of diverse and changing demands on water resources (table 2). Investments will be more strategic, planned within the overall framework of agriculture and rural development.

It is time to abandon the obsolete divide between irrigated and rainfed agriculture. In the new policy approach rainfall will be acknowledged as the key freshwater resource, and all water resources, green and blue, will be explored for livelihood options at the appropriate scale for local communities. Also to be considered is the role of marginal-quality water in improving livelihoods. Rather than thinking of the water flowing out of cities as waste, it needs to be seen as a resource for many poor urban or periurban farmers. We need to consider agriculture as an ecosystem and to recognize the importance of preserving the natural resource base on which agricultural productivity rests. And we need to be cautious in using resources: overpumped aquifers and overdeveloped river basins are showing their limits, presenting a different set of problems.

But to support these changes, investments are required to build knowledge and to reform and develop institutions. Education, research, capacity building, and awareness raising are stepping stones toward better water management in agriculture. A new cadre of policymakers, managers, and extension providers is needed, with staff trained to understand and support producers in water management investments in farms and communities. But investments are not enough. They need to be accompanied by changes in governance and decisionmaking power.

Improving water management in agriculture requires learning by doing and a flexible, adaptive approach. Adaptive management is appropriate for variable resources in a context of continually fluctuating parameters. Adaptive management incorporates an understanding of the variability within systems, as well as long-term and slow-onset changes. It allows for management practices to be responsive to these variations, some of which can be rapid.

table 2 **Evolution of thinking on water management in agriculture**

Past thinking	Current and future thinking
Focused attention, mainly on irrigation options and withdrawals from rivers and groundwater.	Considers options across a spectrum of water management in agriculture, including rainfed and irrigation, and integrating fisheries and livestock. Devotes more attention to managing rainwater, evapotranspiration, and reuse. Views land-use decisions as water-use decisions. Incorporates the interconnectedness of users through the hydrologic cycle.
Treated water for agriculture and for ecosystems as separate.	Treats agriculture as an ecosystem producing multiple services, interacting with ecosystem conservation.
Considered benefits and costs only of food production in a sectoral approach.	Adopts a broader livelihood agenda to increase assets of the poor, provide more voice in decisionmaking, raise incomes, and reduce risk and vulnerability.
Directed mainly at crop production.	Promotes the multiple functions and multiple goals of water in agriculture. Recognizes different roles based on gender, age, class, and caste.
Worked in a political vacuum, imposing single-factor (“magic bullet”) reforms from the outside.	Structures context-specific approaches to negotiating and crafting effective institutions and policies, recognizing the contentious political nature of reforms.
Managed water in a command and control environment.	Makes irrigation services directed, flexible, reliable, and transparent.
Made investments to meet needs of poor people in the form of “interventions.”	Places the means of getting out of poverty into the hands of poor people by focusing on water as a means to raise their own food. Increases participation in markets for higher incomes through diversification and local economic growth, creating more jobs both on and off the farm.
Expanded agricultural land to increase production.	Intensifies agriculture by increasing water and land productivity to limit additional water use and expansion onto new lands.
Saw the state as the responsible unit for resource development and management.	Makes decisions on water interventions more inclusive and transparent. Involves civil society organizations in decisionmaking.
Sidelined biodiversity as somebody else’s problem and purely as a “conservation” issue.	Mainstreams biodiversity and ecosystem services to avoid their loss or mismanagement.
Viewed environmental use of water as “wasted” water.	Includes proper economic valuation of the environmental aspects of water use in tradeoffs and decisions for water use.

Policy action 2 Fight poverty by improving access to agricultural water and its use

Insecure access to reliable, safe, and affordable water keeps hundreds of millions of people from escaping poverty. Most of them rely directly on agriculture for their food and income. Unless bold action is taken, many more smallholder farmers, fishers, herders, and people dependent on wetlands will fall into poverty as rivers dry up, groundwater declines, and water rights are lost.

Broadly conceived, poverty reduction strategies will entail four elements:

- Empowering people to use water better, and targeting the right groups.
- Ensuring the right to secure access.
- Improving governance of water resources.
- Supporting the diversification of livelihoods.

Targeting smallholder farmers—particularly in largely rainfed areas, but also in irrigated areas—offers the best chance for reducing poverty quickly in developing countries. Smallholder farmers make up the majority of the world's rural poor. Often occupying marginal land and depending mainly on rainfall for production, they are sensitive to droughts, floods, and shifts in markets and prices. In regions where agriculture constitutes a large proportion of the economy, water management in agriculture will remain a key element in strategies to reduce rural poverty. Smallholder farmers possess the greatest unexploited potential to directly influence land and water use management.

> **Targeting smallholder farmers—particularly in largely rainfed areas, but also in irrigated areas—offers the best chance for reducing poverty quickly in developing countries**

Focusing on livelihood gains by small-scale, individually managed water technologies holds great promise for poverty reduction in the semiarid and arid tropics. These include small pumps and innovative technologies such as low-cost drip irrigation, small affordable pumps, and small-scale water storage. These are affordable even for some of the poorest members of the community and can be implemented almost immediately, without the long delays of large projects. Private investments in pumps have improved the livelihoods and food security of millions of farmers and pastoralists in Africa and Asia. In the long run these can be viewed as a first step, followed by additional investments in infrastructure.

Clarifying water rights can ensure secure access to water for agriculture for poor women and men when carefully implemented. In certain circumstances collective water rights might be preferable to individual water rights. Redistributive policies can give the rural poor access to assets, markets, and services. Acknowledging customary laws and informal institutions can facilitate and encourage local management of water and other natural resources. The capacity of people to manage their water resources can be enhanced through specific training. Local management should be integrated with basin, regional, and national institutions—and based within the broader context of rural development.

Where there is equity in resource distribution, the poverty reducing impact of improved water management on agricultural productivity growth has been greater. Inequality, particularly gender-based inequality, tempers the effectiveness of poverty reduction efforts. Women produce an estimated two-thirds of the food in most developing countries, yet they often have inadequate access to land, water, labor, capital, technologies, and other inputs and services. This situation is unjust and prevents women from realizing their full potential as human beings and citizens and compromises efforts to target water management for poverty reduction.

Small water management systems, built and operated by communities or individuals from groundwater, river water, and wastewater, are vital to many poor farmers but often are not officially recognized. Increased visibility of irrigation and water management of these informal systems will influence governments to provide policy and technical support and help to ensure poor farmers' continuing access.

> Multiple-use systems for domestic use, crop production, aquaculture, agroforestry, and livestock effectively improve water productivity and reduce poverty

Policymakers need to focus on both design and development of water resources infrastructure from a multiple-use system perspective. By doing so they can maximize the benefits per unit of water for poor women and men and ensure that institutional and legal frameworks guarantee the participation of rural people and marginal groups in all phases of policy development and decisionmaking for infrastructure investments. Multiple-use systems for domestic use, crop production, aquaculture, agroforestry, and livestock effectively improve water productivity and reduce poverty. The contributions to livelihoods, especially for poor households, of these multiple uses are substantial.

Agricultural water research should target poverty head on. It should look at low-cost technologies and practices adapted to accommodate gender and cultural differences. It should examine how to obtain more nutrition per drop—especially important for food security in areas without adequate market access. And it should examine how the capabilities of the poor can be enhanced to cope with floods, droughts, and other water-related hazards.

Fisheries should be better integrated in water resources management. They are an important source of livelihoods and nutrition. The value of freshwater fish production to human nutrition and incomes is far greater than gross national production figures suggest. The bulk of production is generated by small-scale activities, with exceedingly high levels of participation not only in catching and farming but also in the ancillary activities of processing and marketing.

Livestock, too, need to be better integrated in water resources management. In addition to enhancing income and food security, livestock play a big role in livelihood strategies for 70% of the world's rural poor, enabling families to survive crop failure, cope with income shocks, and meet unexpected or major family expenses by selling an animal.

Agricultural water management investments alone cannot eliminate poverty. Many poverty reduction gains come from better credit and insurance, better farm practices, stronger links to markets and support services, and improved health care. So water management approaches need to be better integrated into broader poverty reduction strategies.

Policy action 3 Manage agriculture to enhance ecosystem services

Land-use changes and water diversions for agriculture have been major drivers of the degradation and loss of ecosystems. Greater food production has come at the expense of biodiversity and ecosystem services—regulating, supporting, provisioning, and cultural—that are often important to poor people's livelihoods.

Why manage ecosystem services?

Ecosystem services of agricultural systems include flood mitigation, groundwater recharge, erosion control, and habitats for birds, fish, and other animals, in addition to food production. Many services (pollination, predation) are used as agricultural inputs.

Poor agricultural water management practices can damage ecosystems and their services in many ways. For example:

- River and groundwater depletion and consequent degradation of downstream aquatic ecosystems, including wetlands, estuaries, and coastal ecosystems, with devastating effects on fisheries.
- Drainage of wetlands and discharges of wastewater to surface water–dependent and groundwater-dependent ecosystems.
- Pollution from overuse of nutrients and agrochemicals, with consequences both for terrestrial and aquatic ecosystems and for human health.
- Poor land and water management leading to excessive erosion, causing siltation in rivers, wetlands, and coastal areas—in addition to poor soil conservation limiting green water utilization.
- Loss of natural resource base, affecting people's livelihoods by changing coping strategies and making people more vulnerable to shocks.

Many agricultural water management systems have evolved into diverse agroecosystems, rich in biodiversity and ecosystem services

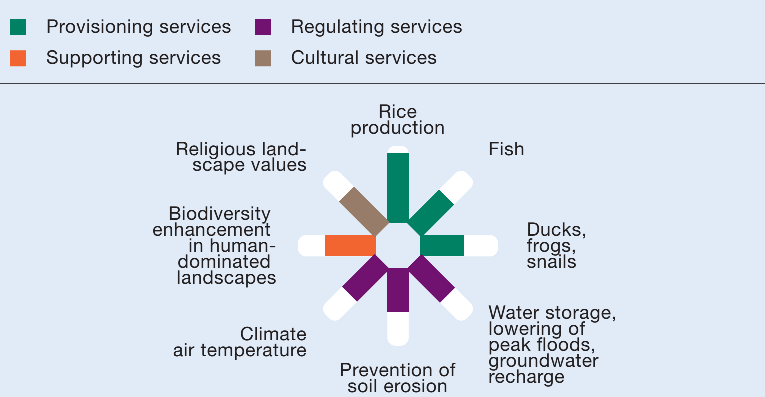
How to manage for diverse agroecosystems

Even so, many agricultural water management systems have evolved into diverse agroecosystems, rich in biodiversity and ecosystem services far beyond food production. There are many examples where areas of paddy rice cultivation are semi-natural wetlands (figure 5).

Strategies for avoiding the adverse impacts:

- *Improve agricultural practices to enhance a range of ecosystem services.* In agroecosystems there is scope to promote services beyond the production of food, fiber, and animal products. Agricultural production does not have to be at the expense of other services provided by water in wetlands and rivers.
- *Align support for maintaining or improving ecosystem services by ensuring that the rural poor realize considerable benefits.* Otherwise, poverty alleviation and healthy ecosystems will seem in competition.
- *Adapt to manage the water used by agroecosystems and to accommodate the uncertainty about ecosystem change.*
- *Improve land and water management to incorporate a better understanding of the importance and role of biodiversity.* Biodiversity underpins ecosystem services, and its proper management is essential to maintaining and improving human well-being. Managing these relationships must be the responsibility of all who use water.
- *Have managers manage for diversity and engineers engineer for diversity.* Diversity is good for economic and ecosystem prosperity, resilience, and sustainability. A way to maintain diversity is to manage agroecosystems to mimic as closely as possible their natural character and state—for example, by releasing environmental flows with a pattern close to the original. Simplifying parts of ecosystems to increase economic output for certain sectors or stakeholders (intense monocropping) is not necessarily

figure **5** **Multifunctionality in rice fields**



Source: Adapted from Foley, J., R. DeFries, G.P. Asner, C. Barford, G. Bonan, S.R. Carpenter, F.S. Chapin, and others, 2005, "Global Consequences of Land Use," *Science* 309 (22 July): 570–74; chapters 6 and 14 in this volume.

bad and can be a productive use of ecosystems. But it must be conducted under a broader strategy that manages ecosystem services overall—and that promotes sustaining and rehabilitating ecosystem diversity.

- *Raise awareness of the role and value of ecosystem services*—through education, information dissemination, and dialogues among stakeholders, sectors, and disciplines.
- *Improve inventories, assessments, and monitoring*, especially of factors related to ecosystem resilience and thresholds that, once crossed, preclude a system from providing a range of services.

Policy action 4 Increase the productivity of water

Increasing water's productivity—gaining more yield and value from water—is an effective means of intensifying agricultural production and reducing environmental degradation. There are reasons to be optimistic. There is still ample scope for higher physical water productivity—getting more produce per unit of water—in low-yielding rainfed areas and in poorly performing irrigation systems, where poverty and food insecurity prevail. Good agricultural practices—managing soil fertility and reducing land degradation—are important for increasing crop per drop. Our assessment of livestock and fisheries reveals scope for improvements in these systems as well—important because of the growing demand for meat and fish.

Reasons for optimism—and caution

There are many well known crop per drop improvements. These include more reliable and precise distribution and application (such as drip) of irrigation water, supplemental and deficit irrigation, improved soil fertility, and soil conservation practices. In smallholder livestock systems, feeding animals crop residues can provide a severalfold increase in water productivity. Integrated approaches are more effective than single technologies.

But caution and care must be mixed with the optimism. Water productivity gains are often difficult to realize, and there are misperceptions about the scope for increasing physical water productivity. For example:

- Much of the potential gain in physical water productivity has already been met in high-productivity regions.
- Waste in irrigation is less than commonly perceived, especially because of reuse of water locally or downstream—farmers thirsty for water do not let it flow easily down the drain.
- Major gains and breakthroughs, as those in the past from breeding and biotechnology, are much less likely (box 3).
- A water productivity gain by one user may be a loss to another—upstream gain may be offset by a loss in fisheries, or the gain may put more agrochemicals into the environment.

Increasing water's productivity is an effective means of intensifying agricultural production and reducing environmental degradation

There is greater reason to be optimistic about increasing economic water productivity—getting more value per unit of water. How? By switching to higher value agricultural uses. Or by reducing costs of production. Integrated approaches—agriculture-aquaculture systems, better integrating livestock in irrigated and rainfed systems, using irrigation water for household and small industries—all are important for increasing the value and jobs per drop. One example: better veterinary services can improve water productivity because healthier animals provide more benefits per unit of water.

Higher physical water productivity and economic water productivity reduce poverty in two ways. First, targeted interventions enable poor people or marginal producers to gain access to water or to use water more productively for nutrition and income generation. Second, the multiplier effects on food security, employment, and income can benefit the poor. But programs must ensure that the gains reach the poor, especially poor rural women, and are not captured by wealthier or more powerful users. Inclusive negotiations increase the chance that all voices will be heard.

With the right policy and institutional environment

Many known technologies and management practices promise considerable gains in water productivity. Achieving those gains requires a policy and institutional environment that

box 3 | Can biotechnology improve water productivity?

For the Comprehensive Assessment of Water Management in Agriculture we conclude that only moderate impacts on crop water productivity can be expected from genetic improvements to plants over the next 15–20 years. But these improvements will reduce the risk of crop failure. Gains from breeding nontraditional crops and fish can improve water productivity. They can be achieved through slow conventional breeding, but be sped up by using appropriate biotechnological tools, of which genetically modified organisms are only one means. Greater, easier, and less contentious gains are to be made through better management, because there is already such a wide gap between practice and biophysical potential.

aligns the incentives of various users at different scales—from field to basin to country—to encourage the uptake of new techniques and to deal with tradeoffs. It requires policies that:

- *Overcome risks*. Farmers face low prices for their output, uncertainties in markets, and uncertainties in water distribution and rain. Managing water reduces some of these risks. Better market access and information help. But some sort of insurance may also be needed.
- *Provide incentives for gains in water productivity*. The incentives of producers (more water for more produce and income) are often much different from those of broader society (less water for agriculture, more for cities and the environment). Rather than trying to charge farmers more for water use, the parts of society benefiting from reallocations may need to compensate farmers for less water use in agriculture.
- *Adjust basin-level water allocation policies*. Changes in practices aimed at increasing water productivity result in changes in other parts of a river basin. Increasing agricultural production by using saved water or increasing water harvesting may leave less water for downstream users—such as coastal fisheries. Before implementing change, there must be an understanding of basin hydrology and an overall perspective on water allocation programs, so that there is a real increase in basin-level water productivity, not just local gains.
- *Target the poor with sustainable, water productivity-enhancing practices*. Wealthier and more powerful users tend to capture gains, especially in ill-devised development or relief programs. A long-term, carefully designed program—to integrate technologies, practices, and markets, to reduce risks, and to ensure profitability—is required for pro-poor gains.
- *Look for opportunities outside the water sector*. Many possibilities exist for addressing the vulnerability, risk, markets, and profitability of agricultural enterprise.

> **Many known technologies and management practices promise considerable gains in water productivity. Achieving those gains requires a policy and institutional environment that aligns the incentives of various users at different scales**

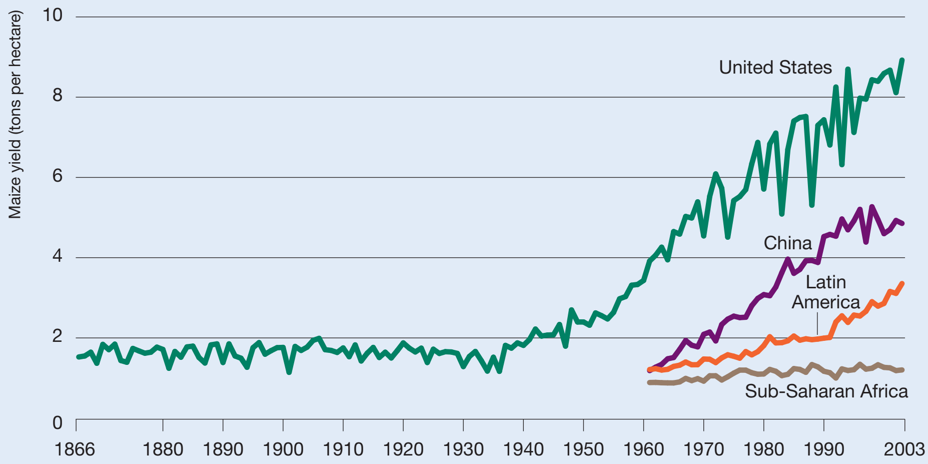
High priorities for water productivity improvement include:

- Areas where poverty is high and water productivity low, where the poor could benefit—much of Sub-Saharan Africa and parts of South Asia and Latin America (figures 6 and 7).
- Areas of physical water scarcity where there is intense competition for water—the Indus Basin and Yellow River—especially through gains in economic water productivity.
- Areas with little water resource development, such as Sub-Saharan Africa, where a little water can make a big difference.
- Areas of water-driven ecosystem degradation, such as falling groundwater tables and drying rivers.

Policy action 5 Upgrade rainfed systems—a little water can go a long way

About 70% of the world's poor people live in rural areas where livelihood options outside of agriculture are limited. Many rural poor rely mainly on rainfed farming for food, but variable rainfall, dry spells, and droughts make rainfed farming a risky business (map 3). Better management of rainwater, soil moisture, and supplemental irrigation is the key to helping the greatest number of poor people, for three main reasons:

figure **6** | **Sub-Saharan Africa has yet to "take off" as Asia and Latin America did in the green revolution and industrial countries did much earlier**



Source: U.S. data, U.S. Department of Agriculture's National Agricultural Statistics Service; all other countries and regions, FAOStat.

figure **7** | **The biggest potential for water productivity gains is in very low-yielding areas, which typically coincide with poverty**

Source: Adapted from Zwart, S.J., and W.G.M. Bastiaanssen, 2004, "Review of Measured Crop Water Productivity Values for Irrigated Wheat, Rice, Cotton and Maize," *Agricultural Water Management* 69 (2): 115–33; chapter 7.

- It cuts the yield losses from dry spells—which can claim one of every five harvests in Sub-Saharan Africa.
- It gives farmers the security they need to risk investing in other inputs such as fertilizers and high-yielding varieties. Farmers dare not risk the little they have buying inputs for a crop that may fail for lack of water.
- It allows farmers to grow higher value market crops, such as vegetables or fruits. These are more sensitive to water stress and require costlier inputs. Farmers can then move away from low-value staple foods and earn cash incomes.

> Better management of rainwater and soil moisture is the key to helping the greatest number of poor people

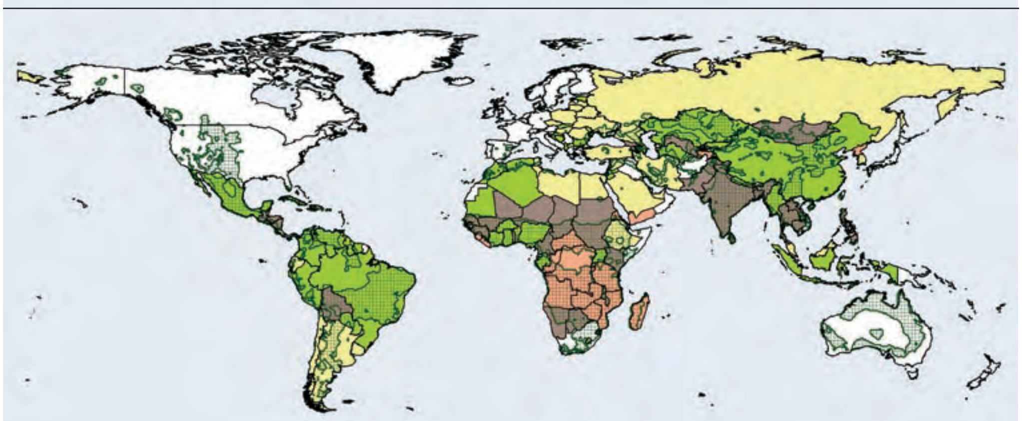
Improving agricultural productivity in areas that depend on rainfall has the greatest potential to reduce poverty and hunger, especially for Sub-Saharan Africa and large parts of Asia. Current yields in many rainfed settings are low, and improving rainfed farming could double or quadruple yields. Such yields "gaps" are greatest for maize, sorghum, and millet in Sub-Saharan Africa. Closing those gaps promises huge social, economic, and environmental paybacks.

Slow uptake

While numerous studies document the benefits of upgrading rainfed agriculture by soil and water conservation practices, water harvesting, and supplemental irrigation, these tend to be isolated successes. Adoption rates have been low for four main reasons: the low profitability of agriculture, lack of markets, relatively high labor costs, and high risks. Past efforts have not changed national yields very much. Needed now is to improve farmers' access to markets,

map **3** | **Undernutrition is high in semiarid and dry subhumid climates subject to variable rainfall, dry spells, and droughts**
(Undernourished as share of total population, 2001/02)

Less than 5% | 5%–20% | 20%–35% | More than 35% | Koeppen climate zones savannahs/steppes



Note: Semiarid and dry subhumid hydroclimates include savannah and steppe agroecosystems. These regions are dominated by sedentary farming subject to the world's highest rainfall variability and occurrence of dry spells and droughts.
Source: UNStat database, 2005, United Nations Statistical Division, http://unstats.un.org/unsd/default.htm; chapter 8.

credits, and inputs (fertilizers). But the first step would be to target water—because without having water where and when it is needed, rural people risk crop failure and hunger.

Investments to reduce vulnerability to water-related risks and improve productivity in rainfed areas are compelling for equity and for the environment. Investment costs per hectare are lower in rainfed areas than in irrigated areas. The systems can be quickly implemented, yield fast and high marginal returns, and slash poverty. The technologies for upgrading rainfed agriculture already exist—and in some cases have been around for thousands of years. For example, conservation tillage, which disturbs the soil as little as possible to avoid soil moisture loss, is practiced on 45 million hectares, mostly in South and North America. In Rajasthan, India, the restoration of traditional water-harvesting structures that had fallen into disuse allowed farmers to gain a second cropping season, improve their productivity, and reduce groundwater pumping costs.

Investments to reduce vulnerability to water-related risks and improve productivity in rainfed areas are compelling for equity and for the environment

Realizing the potential of existing rainfed areas reduces the need for water withdrawals for new large-scale irrigation development, although improving rainfed production through water harvesting and supplemental irrigation also requires infrastructure, if smaller and more distributed.

Realizing this potential also requires measures of risk mitigation. Agricultural production in semiarid areas is highly vulnerable to variable climate and to future climate change. And too much reliance on rainfall may reduce farmers' ability to adapt to change. Water-harvesting techniques are useful to bridge short dry periods, but longer dry periods may lead to crop failure. Because of this risk, farmers are reluctant to invest in fertilizers, pesticides, and labor, creating a circular pattern of risk and poverty. Adding an irrigation component is often an important element of upgrading rainfed agricultre.

Nor is upgrading rainfed agriculture free of negative environmental consequences. Depending on the setting, harvesting rainwater increases the amount of water depleted by crops, leaving less for runoff to rivers and lakes or for groundwater recharge. Impacts on downstream resources need site-specific assessments.

Accelerating progress

But with the right incentives and measures to mitigate risks for individual farmers, water management in rainfed agriculture holds large potential to increase food production and reduce poverty, while maintaining ecosystem services.

Key steps for tapping rainwater's potential to boost yields and incomes:

- *Make more rainwater available to crops when it is most needed.* This can be done by capturing more rainfall, storing it for use when needed, adding irrigation to rainfed systems, using it more efficiently, and cutting the amount that evaporates unused. Water harvesting, supplemental irrigation, conservation tillage, and small-scale technologies (treadle pumps and simple drip-irrigation kits) are all proven options. For example, small investments providing 100 liters per square meter for supplemental irrigation during dry spells when crops are flowering or at the grain-filling stage could more than double agricultural and water productivity. This is much less than what is required for typical full-time irrigation.
- *Build capacity.* Water planners and policymakers need to develop and apply rainwater management strategies, and extension services need the skills and commitment

to get rainwater-exploitation techniques out to farmers and to work with them to adapt and innovate for their specific context. This has been a blind spot of river basin management.

- *Expand water and agricultural policies and institutions.* Rainwater management in upper catchments and on farms should be included in management plans, and supporting water institutions are needed.

> The challenge for irrigated agriculture in this century is to improve equity, reduce environmental damage, increase ecosystem services, and enhance water and land productivity in existing and new irrigated systems

Policy action 6 Adapt yesterday's irrigation to tomorrow's needs

In large parts of the developing world irrigation is still the backbone of rural economies (map 4). While irrigation will continue to be critical to meeting global food needs and to sustaining rural economies, the conditions that led to massive public investment in large-scale irrigation in the second half of the 20th century have changed greatly.

The era of rapid expansion of large-scale public irrigated agriculture is over: a major new task is adapting yesterday's irrigation systems to tomorrow's needs. More than anything, irrigation must respond to changing requirements, serving an increasingly productive agriculture. Reforming water management institutions is a priority—changing incentive structures and building capacities to meet new challenges.

Why invest in irrigation?

Investments in irrigation, though still needed, must become more strategic (box 4). Irrigation has to be seen in the context of other development investments, taking into consideration the big picture of costs and benefits, including social, cultural, economic, and environmental aspects. Also to be considered is the full spectrum of irrigation options—from large-scale systems providing water for all or most of a crop's needs to small-scale technologies supplying water to bridge dry spells in rainfed areas.

Improving the performance of existing systems and adding new irrigation can reduce poverty by increasing farmer incomes, providing employment for the landless, reducing staple food prices, and contributing to overall economic growth by inducing secondary benefits, such as boosting agroindustry.

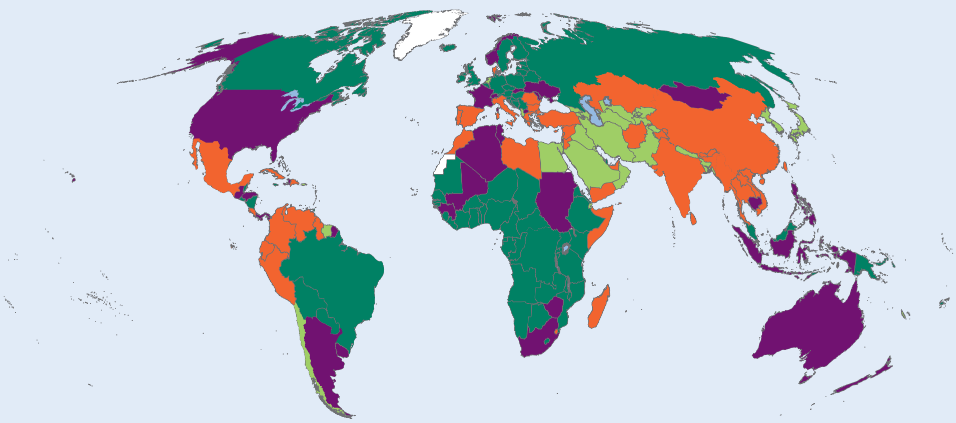
What kind of investment and how much?

The challenge for irrigated agriculture in this century is to improve equity, reduce environmental damage, increase ecosystem services, and enhance water and land productivity in existing and new irrigated systems. Countries need to tailor irrigation investments to local circumstances—reflecting the stage of national development, integration into the world economy, degree of poverty and equity, availability of land and water, share of agriculture in the national economy, and comparative advantage in local, regional, and world markets.

In some areas there is scope for expanding irrigation, especially in Sub-Saharan Africa. In others the challenge is to get more from existing infrastructure—through technical upgrading and better management practices.

map **4** | **Area under irrigation as a share of cultivated land**

Less than 5% | 5%–15% | 15%–40% | More than 40% | No data | Inland water bodies



Source: Food and Agriculture Organization, 2006, FAOSTAT database, http://faostat.fao.org; chapter 9.

box **4** | **Four reasons to invest in irrigation**

1. To reduce poverty in rural areas. In countries and regions that rely on agriculture for a large part of their GDP (most of Sub-Saharan Africa), raising agricultural productivity is the most viable option for reducing poverty, and irrigation development can act as a springboard for economic development. Irrigation schemes can facilitate multiple uses of water that combine agriculture with livestock, fisheries, and other income-generating activities to enhance rural incomes and sustainability.

2. To keep up with global demand for agricultural products and adapt to changing food preferences and societal demands. Feeding an additional 2–3 billion people by 2050 will require greater productivity on existing irrigated lands and some expansion of irrigation. Urbanization in many developing countries shifts demand from staple crops to fruits, vegtables, and livestock products.

3. To adapt to urbanization, industrialization, and increasing allocations to the environment. Increasing competition for water will require investments that enable farmers to grow more food with less water.

4. To respond to climate change. Climate variability and extremes may require large water storage facilities, further irrigation development, and changes in the operation of existing schemes.

While in places these reasons will justify investments in new irrigated infrastructure, the bulk of future investments will focus on preserving and modernizing existing irrigation systems to improve their performance and adapt them to their new function. This is particularly relevant to South Asia, where yields are low, inequity is substantial, and water logging and salinization are pervasive.

Productivity gains are possible across the full spectrum of existing irrigated agriculture, driven by the market and incentives that lead to profitable farm incomes. Large-scale surface irrigation systems need to incorporate better information and water control, have more of a service-oriented culture, and be more responsive to the needs of farmers, livestock keepers, fishers, and those who use water for small industry or domestic use.

Irrigation management must also increase the reliability of water supply. More finance will be required for well conceived improvements in water control and delivery, automation and measurement, and for better training and professional development of staff.

> In some areas there is scope for expanding irrigation—in others the challenge is to get more from existing infrastructure

More investments in technical and managerial upgrading are required in countries with aging irrigation infrastructure. Investments in drainage are likely to continue at fairly modest levels. There will thus be considerable tension between financial needs and a government's willingness and ability to finance them.

Manage groundwater sustainably

Thanks to a global groundwater boom, millions of farmers and pastoralists in Asia and Africa have improved their livelihoods and food security. Groundwater has contributed significantly to growth in irrigated areas since the 1970s, especially in South Asia and the North China Plains, regions with high concentrations of rural poverty. Overwhelming evidence from Asia suggests that groundwater irrigation promotes greater interpersonal, intergender, interclass, and spatial equity than does large surface irrigation.

But the boom has turned to bust. Runaway expansion in groundwater irrigation poses an environmental threat but remains a mainstay of smallholder agrarian livelihoods. The energy-groundwater nexus has created a curious political economy paradox: soaring energy prices may help save the aquifers but threaten groundwater-based livelihood systems. Improving the energy efficiency of groundwater irrigation may help save aquifers and livelihoods. In those areas current trends in groundwater use will not be sustained unless accompanied by far more intensive resource management.

But in other areas groundwater's potential could be further exploited. In areas with good aquifers and recharge and a high prevalence of poverty, such as the Gangetic plains, groundwater irrigation remains an important development strategy. How best to manage it? Participatory approaches to sustainable groundwater management will need to combine supply-side measures (artificial recharge, aquifer recovery, interbasin transfers) with demand-side measures (groundwater pricing, legal and regulatory control, water rights and withdrawal permits, water-saving crops and technologies).

Supply-side measures have proved easier to implement than demand-side measures—even in technologically advanced countries. But the only way to relax aquifer systems to an acceptable degree may be to reduce irrigated areas, improve farming practices, and switch to water-saving crops—difficult to implement, especially in developing countries.

Make the best use of marginal-quality water where it matters

Freshwater of marginal quality is an important source of water. Millions of small-scale farmers in urban and periurban areas of developing countries irrigate with wastewater from residential, commercial, and industrial sources, in many areas not treated before use. Millions of other farmers in deltaic areas and tailend sections of large-scale irrigation schemes irrigate with a blend of canal water, saline drainage water, and wastewater. Many of them cannot control the volume or quality of water they receive within a week, month, or season.

Wastewater reuse in agriculture is difficult to assess, but it is clearly important in several areas, largely in arid and wet environments. In Hanoi, Viet Nam, 80% of vegetables are irrigated with water mixed with wastewater, and in Kumasi, Ghana, recorded informal irrigation, much of it using wastewater, covers 11,900 hectares, about a third of the officially recorded irrigated area of the country. There are three main policy approaches for improving management of marginal-quality water: reduce the amount of marginal-quality water generated, minimize the risks when it is used in agriculture, and minimize the risks when handling food grown with such water.

> Reforms have focused on formal irrigation or water management policies and organizations and have ignored the many other factors that affect water use in agriculture—policies in other sectors, user institutions, and broader social institutions

Change the governance of irrigation

Needed, above all, is to change the governance of irrigation. With the general decline in construction of new systems and the shift of management responsibilities to users, the role of public irrigation agencies is rapidly changing. Activities in planning and designing systems, contracting for and supervising civil works, and delivering water to farms will be less important. New responsibilities will include resource allocation, bulk water delivery, basin-level management, sector regulation, and the achievement of global social and environmental goals such as the Millennium Development Goals.

Policy action 7 Reform the reform process—targeting state institutions

The state will retain its role as the main driver of reform, but it is also the institution most in need of reform. There are cases of "failing states" in addition to situations where structural adjustment has brought major transformations to the detriment of agriculture and water management. The state must take responsibility for ensuring greater equity in access to water resources and foster investments to reduce poverty. Protecting essential ecosystem services is also vital, especially to poor people's livelihoods.

The last 30 years of attempts at agricultural water reform have, with few exceptions, shown disappointing results. Despite repeated calls for decentralization, integration, reform, and better governance, implementation has not been entirely successful, and much remains to be done to achieve effective changes (box 5).

The approach to reform needs to be reconsidered. Instead of the linear, prescriptive models that have dominated thinking for the past several decades, the Comprehensive Assessment proposes a more nuanced and organic approach to institutional reform—one grounded in the local socioeconomic, political, and physical environment and cognizant of the dynamic nature of institutions (box 6).

Why have previous approaches so often failed?

Many reforms have not taken into account the history, culture, environment, and vested interests that shape the scope for institutional change. They have often been based

box 5 | **Prescriptive models of reform often fail to deliver expected benefits**

- *Irrigation management transfer*. To reduce government expenditure and improve irrigation performance, many countries have pursued a policy of transferring irrigation management from the state to user groups (water user associations or farmer organizations).
  This has demonstrated potential, but the results have been mixed.
- *River basin organizations.* Centralized basin organizations have been widely touted as the ideal organizational model for managing competition for water and for implementing integrated water resources management.
  Countries would do well to consider placing more emphasis on developing, managing, and maintaining collaborative relationships for basin governance—building on existing organizations, customary practices, and administrative structures.
- *Pricing irrigation water.* Pricing irrigation water has been promoted as the way to achieve water-use efficiency and to cover the costs of construction and operation and maintenance of infrastructure.
  Implementation has frequently foundered on political opposition, compounded by difficulties in measuring water deliveries and collecting fees from large numbers of small users. Applied as a blanket measure, pricing—at a level to be effective as a demand-management mechanism—risks aggravating water deprivation and poverty.
- *Tradable water rights*. The other aspect of pricing that has attracted attention is related to water markets. In countries where water rights exist and are separate from land rights, markets can, in theory, ensure efficient reallocation of water among sectors through trading.
  In practice, water trading has thus far only reallocated small volumes of the resource (less than 1% a year of permanent entitlements in Australia and the western United States). Based on experience thus far, water markets are unlikely to have a big impact on agricultural water use in Asia or Sub-Saharan Africa in the coming 20–30 years.

on "blueprint" solutions—solutions that follow a model that may have been successful elsewhere. Another reason reforms fall short is a focus on a single type of organization rather than the larger institutional context. Focusing on formal irrigation or water management policies and organizations, most reforms have ignored the many other factors that affect water use in agriculture—policies and government agencies in other sectors, informal user institutions, and the macroeconomic environment and broader social institutions.

Other common stumbling blocks include:

- *Inadequate support for reform at required levels*. Change requires support at the policy and decisionmaking level and at the implementation level.
- *Inadequate capacity building and incentives for change*. For individuals and organizations to change their way of doing things, they often need new skills and knowledge.
- *Repeated underestimation of the time, effort, and investment required to change*. Particularly for reforms tied to time-bound, donor-funded projects, there is a tendency to expect too much too quickly. The result: reforms are prematurely judged unsuccessful and are left incomplete or abandoned.

box 6 | **Seven imperatives for today's agricultural water management**

1. Get technical water bureaucracies to see water management not just as a technical issue but also as a social and political issue. This would require meeting the multiple water needs of poor women and men—for growing food, for drinking, for enabling hygiene and sanitation, and for generating income through a range of activities.

2. Support more integrated approaches to agricultural water management. Examples include managing water to enhance ecosystem services in addition to crop production, incorporating livestock and fisheries into water management, improving rainwater management and encouraging investments to upgrade rainfed production, and supporting systems and services that encompass multiple water uses, safe reuse of wastewater, and joint use of surface water and groundwater.

3. Create incentives for water users and government agency staff to improve the equity, efficiency, and sustainability of water use.

4. Improve the effectiveness of the state, particularly in its regulatory role, and find the right balance between action by the state and by other institutional actors.

5. Develop effective coordination and negotiation mechanisms among the state, civil society, and private organizations in water development and management and in related sectors.

6. Empower women and marginalized groups who have a stake but currently not a voice in water management. Specific support institutions are needed to progress toward the Millennium Development Goals.

7. Build coalitions among government, civil society, and private and community users—and harness market forces for successful reform.

Crafting reform strategies

Moving forward requires strategies for institutional and policy reform that take into account today's (and yesterday's) realities. First, reform is an inherently political process. Second, the state is the primary, but not the only, driver in reform. Third, the pluralism and social embeddedness of institutions affect water development, management, and use. Fourth, capacity building, information sharing, and public debate are essential. Fifth, implementation plans must be responsive to new knowledge and opportunities.

Policy action 8 Deal with tradeoffs and make difficult choices

Water management today requires making difficult choices and learning to deal with tradeoffs. In reality, win-win situations will be hard to find. But a consultative and inclusive process for reaching decisions can help ensure that tradeoffs do not have inequitable effects.

Reform and change are unpredictable. Even with the best science there will always be a high level of uncertainty about external drivers and about the impacts of decisions. One of the biggest drivers will be climate change, which will affect productivity and ecosystems and will require policies and laws in response to change. Water management institutions must take an adaptive management approach. They need the capacity to identify danger signs and the flexibility to change policy when better understanding emerges. Informed multistakeholder negotiations are required to deal with tradeoffs, and innovative means to apply decisions.

The big tradeoffs

- *Water storage for agriculture—water for the environment*. The Comprehensive Assessment points to the need for more storage of water including, as locally appropriate, that behind large and small dams, in groundwater, and by water harvesting—albeit at a slower rate. Storage will be a widespread response to changing rainfall in many regions as a result of climate change. But it will also take water away from environmental uses.
- *Reallocation—overallocation*. Providing access to water and safeguarding rights to water were identified as key poverty concerns. But in many "closed" basins resources are already overallocated, making allocation decisions particularly difficult. New allocations of water in closed basins will require renegotiating water allocation. Who will benefit the most from water gains? And how will losses be compensated?
- *Upstream—downstream*. Freshwater fisheries, environmental flows, and coastal areas are all affected by developments upstream in river basins, often without discussion. Part of the difficulty is that cause-effect relations are difficult to identify, so actions are taken without knowing the consequence. And poor fishers lack the voice or political clout to retain their water.
- *Equity—productivity*. Promoting productive and efficient agriculture tends to favor the wealthy, and promoting more equitable agriculture is not necessarily productive.
- *This generation—the next ones*. Some choices made now can be a benefit, or a cost, for future generations. With groundwater levels dropping in many areas, mining it further today may mean that someone tomorrow will not enjoy the same resource. But encouraging economic growth by using groundwater now could mean that people in the future can move more easily away from dependence on groundwater.

The Comprehensive Assessment finds that more balanced outcomes are generally reached when there is a mix of political space allowed by the state and active organization of civil society to defend causes or population groups

Making difficult choices

The state's role in driving reform may be critical, but it cannot make changes alone. Alone, writing new laws or passing administrative orders achieves little. Good governance is rarely triggered by well intentioned policy documents or participatory rhetoric. The Comprehensive Assessment finds that more balanced outcomes are generally reached when there is a mix of political space allowed by the state and active organization of civil society to defend causes or population groups.

There is a need to identify incentives or mechanisms to compensate those who stand to lose in water allocation decisions. The concept of payment for environmental services has given ecosystems a voice in this.

Elements critical for negotiating tradeoffs:

- *Foster social action and public debate*. Public debate based on shared information creates more trust, legitimacy, and understanding of the reasons for change—increasing the likelihood of implementation. Such debate creates opportunities to include poor stakeholders—those with the most to gain (or lose), among them the too-often unrecognized landless, fishers, pastoralists, and those dependent on wetland and forest ecosystem services.

- *Develop better tools for assessing tradeoffs*. Such tools can help in deciding which ecosystem services in a particular area most benefit society. Existing tools include cost-benefit analyses, valuation of nonmarket services, assessments of risk and vulnerability, and models for estimating the water flows required by wetlands.
- *Share knowledge and information equitably*. More data need to be generated, turned into reliable information, and shared widely with stakeholders to empower them through better awareness and understanding—that is, through knowledge. New skills and capacities in water management institutions are critical—at a time when government capacities to attract and hold people with this expertise are weakening.

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