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Investing in water for food, ecosystems, and livelihoods: An overview of the comprehensive assessment of water management in agriculture

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ABSTRACT

The authors of the recently completed Comprehensive Assessment of Water Management in Agriculture (CA) concluded that there are sufficient water resources to produce food for a growing population but that trends in consumption, production and environmental patterns, if continued, will lead to water crises in many parts of the world. Only if we act to improve water use will we meet the acute fresh water challenge. Recent spikes in food prices, partially caused by the increasing demand for agricultural products in non-food uses, underline the urgent need to invest in agricultural production, of which water management is a crucial part. The world experienced similar pressure on per capita food supplies and food prices in the 1960s and 1970s, but the challenges now are different than those we experienced 50 years ago. The world's population is substantially larger, there are many more people living in poverty, and the costs of many agricultural inputs are much higher. The current situation and the long-term outlook require a fresh look at approaches that combine different elements such as the importance of access to water for the poor, providing multiple ecosystem services, rainwater management, adapting irrigation to new needs, enhancing water productivity, and promoting the use of low-quality water in agriculture. This special issue highlights the analysis behind a number of policy options identified by the CA, a five-year multi-disciplinary research program involving 700 scientists. This introductory article sets the background and context of this special issue, introduces the key recommendations from the CA and summarizes the papers in this issue.

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1. Introduction

Investments in water for agriculture have made a positive contribution to rural livelihoods, food security and poverty reduction (Molden, 2007). During the second half of the 20th century food production outpaced population growth, with some 78% of the production growth over the period 1961–1999 deriving from yield increases (Bruinsma, 2003) as opposed to agricultural land expansion. Higher yields have been achieved, in part, due to the expansion of irrigated areas and improvements in water management on irrigated lands. The area equipped with irrigation expanded from 139 million ha in 1961 to 277 million ha in 2003 (FAO, 2007). Food prices – in absolute and real terms – have fallen over the past two decades, though recently prices have risen sharply, due partly to increasing demand for agricultural products in non-food uses. During the last 50 years, productivity gains have generated higher yields and incomes for food producers, while consumers have benefited through lower food prices. Throughout those years, irrigation development helped alleviate poverty by creating employment opportunities, lowering food prices, and increasing the stability of farm output (Lipton et al., 2003; Hasnip et al., 2001; Hussain, 2005). Investments in irrigation have increased rural incomes, resulting in greater demands for non-farm goods and services. Bhattarai et al. (2007) estimate this multiplier effect to be as high as 2.5–4.

From a global perspective the benefits from investments in water have exceeded the costs, but the gains could have been more equitably distributed (Molden et al., 2007). In 2004, 850 million people were undernourished, most of whom live in rural areas in developing countries (FAO, 2004). Globally, agricultural productivity has increased during the past 50 years, but regional differences are considerable. For example, maize yields started rising before the 1940s in the US, in the 1960s in China, and in the 1970s and 1990s in Latin America. By contrast, maize yields have hardly changed in Sub-Saharan Africa (Fig. 1).

While many investments in irrigation and agricultural management have improved productivity and enhanced livelihoods, some have been unsuccessful and some have generated notable external costs. Some poorly conceived or poorly implemented water management interventions have incurred high social and environmental costs, such as inequity in the allocation of benefits and undesirable impacts on natural resources. In some cases, common

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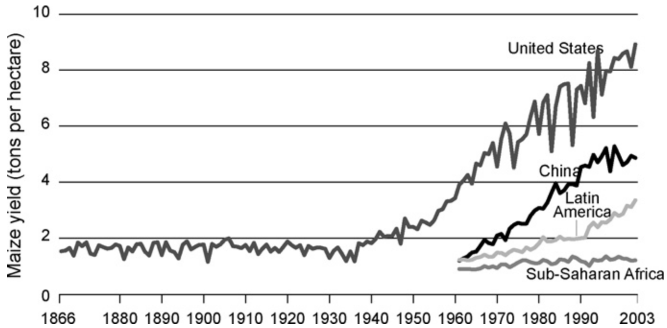

Fig. 1. Growth in maize yields in USA, China, Latin America and Sub-Saharan Africa. Source: Molden, D. 2007.

pool resources such as rivers and wetlands, that are important for poor fishers and resource gatherers, have been appropriated for other uses, resulting in a loss of livelihood opportunities (Gowing et al., 2006). Some communities have been displaced, especially in areas behind dams, without adequate compensation (World Commission on Dams, 2000).

Many of irrigation's negative environmental impacts arise from the diversion of water away from natural aquatic ecosystems, such as rivers, lakes, oases, and other groundwater-dependent wetlands. The direct and indirect negative impacts have been well documented, including salinization, channel erosion, declines in biodiversity, introduction of invasive alien species, reduction of water quality, genetic isolation through habitat fragmentation, and reduced production of floodplains and inland and coastal fisheries (Richter et al., 1997; Revenga et al., 2000; Bunn and Arthington, 2002; Pimentel et al., 2004; MEA, 2005; Khan et al., 2006; Falkenmark et al., 2007). One challenge in moving forward is to determine the best ways for improving agricultural productivity and enhancing livelihoods, while protecting natural resources and sustaining environmental amenities. This challenge might be described also as seeking the optimal balance between productivity gains and environmental costs. It is likely unhelpful to consider only one aspect of interventions in agricultural water management. We must consider the farm-level and societal costs and benefits, and we must evaluate inevitable tradeoffs as we seek the optimal forms and levels of public interventions.

2. Trends and challenges ahead

As noted above, the challenges today are markedly different from 50 years ago. In the past, the fear of famines was a major driving force behind new water developments to increase agricultural production (Barker and Molle, 2004). New challenges have come to the fore: changing diets, increasing water scarcity, urbanization and migration, agricultural transformation, climate change, energy policy, environmental restoration.

2.1. Changing diets and increasing food demands

As incomes rise, food habits change in favour of more nutritious and more diversified diets. Generally this leads to a shift in consumption patterns away from cereals toward livestock products and high-value crops such as fruits, vegetables, sugar, and edible oils (Rosegrant et al., 2002; Pingali, 2004). While the trends in diets follow similar patterns, regional and cultural differences are pronounced. Considerable uncertainties remain regarding some of the major factors driving future food and feed demand. Cereal demand projections range from 2800 million tons to 3200 million tons by 2050, an increase of 55–80% from today. Meat demand projections vary between 375 million tons and 570 million tons by 2050, an increase of 70–155%[1] compared to 2000. Sugar, oil, vegetable and fruit demand are projected to increase by 70–110% (De Fraiture et al., 2007).

2.2. Urbanization

In the 1960s two-thirds of the world's population lived in rural areas, and 60% of the economically active population worked in agriculture. Today, half of the people live in rural areas, and just a little more than 40% of the economically active population depend directly on agriculture (FAO, 2007). By 2050 two-thirds of the world's people will live in cities, but global averages will mask considerable regional variation. In many poor countries in Sub-Saharan Africa and South Asia, the rural population will continue to grow until about 2030, and the number of people depending on agriculture will continue to increase. Urbanization increases competition for water between the urban and agricultural sectors, and changes the production structure of agriculture.

2.3. Structural changes

Changes in global markets, trade policies and the spread of globalization will determine the future profitability of agriculture. While grain production will remain important, a variety of shifting niche markets will emerge, creating opportunities for innovative entrepreneurial farmers, where suitable infrastructure and national policies are in place. In some countries, where other sectors of the economy have a competitive advantage, the contribution of farming to the national economy will shrink, and this may have significant implications for smallholders and subsistence farmers who rely on extension, technology, and regional markets. Yet agricultural development remains the single most promising engine of growth in most sub-Saharan countries. To ensure the sustainability of the agriculture sector in many of these countries, investments in technology and capacity building are needed, along with policies that make farming profitable (Molden et al., 2007).

2.4. Climate change

Climate change will impact many aspects of society and the environment, directly and indirectly, with particular influence on water resources and agriculture. Changes in average temperatures, shifting patterns of precipitation, and changes in the frequency and intensity of extreme weather events can impact agriculture in ways that are not completely predictable. However, it seems likely that water availability for agriculture will be considerably reduced in semi-arid and arid areas, with major consequences for agriculture in Sub-Saharan Africa.

Estimates of the future impacts of climate change and thoughtful strategies for adapting to those impacts must be incorporated into project planning efforts. Public policies and investments regarding infrastructure, public management of projects and resources, and policies that influence human behaviour must be informed by careful consideration of the potential impacts of changes in climate. Investments in water storage and control will be important components of rural development strategies that respond to climate change. Policies and laws designed to reduce greenhouse gas emissions or adjust to a changing climate will have both intended and unintended impacts that must be considered in the context of the resources required to achieve food production goals. For example, investments in biofuels and other projects under the clean development

[1] The wide range is explained partly by substantial uncertainty in income projections, as meat consumption is highly correlated with income.

mechanism (CDM) will reduce the rate of climate change, but will also have significant impacts on water and land (Zomer et al., 2006).

2.5. Volatile energy prices

Fluctuating energy prices impact agriculture, and thus, agricultural water management, in different ways. First, as the demand for alternative energy sources, including hydropower and energy from biomass increases, so does the demand for water; with implications also for water allocation among competing sectors. Second, the cost of pumping groundwater, a major input in agricultural production around the world, increases. Third, when energy prices increase, the viability of desalinization as a source of water for irrigation and other uses declines. Finally, fertilizer prices and the unit costs of other petroleum-based inputs rise with increases in energy prices.

At present the contribution of biofuels to the world's energy supply is very modest, but might increase as a result of rising energy prices, geopolitics, and public concerns regarding the impacts of greenhouse gas emissions. This potentially leads to more intensive competition for land and water resources between food and fuel, particularly where energy demand is high and water is scarce, such as in India and China (De Fraiture et al., 2008). Recent increases in global food prices are due partially to increased production of biofuels (Von Braun, 2008).

2.6. Fluctuating food prices

After declining for the past two decades, the prices of major staple grains began rising sharply in 2007, reached a peak in 2008, and have moderated somewhat in the first half of 2009. In the first quarter of 2008 the price of rice nearly tripled (ADB, 2008). High food prices are a major problem for developing countries that rely heavily on food imports and on poor people who spend most of their income on food. Recent increases in food prices have led to food riots and, according to some estimates, have driven 110 million persons into poverty, while increasing the world's undernourished population by 44 million (Nellemann et al., 2009).

Factors causing the sharp rise in food prices include high oil and energy prices, increasing food demand, speculation in volatile markets, supply shocks due to recent droughts, and inadequate investments in the agricultural sector. The contribution of each factor is disputed. For example, estimates of the impact of the increasing demand for biofuels range from 3% to 70%. The International Food Policy Research Institute (IFPRI) suggests the contribution is 30% (Rosegrant, 2008). Others claim the price spike is at least partly due to complacency and the decline in agricultural investments over the past decade. Until recently, public investment in irrigation has been stagnating across Asia (Faurès et al., 2007), and the results of irrigation investments have been mixed in Sub-Saharan Africa (World Bank, 2007). Whatever the exact causes of the recent food crisis, it is clear that renewed attention to agricultural productivity is needed. Agricultural water management will play an increasingly important role in producing sufficient food supplies.

2.7. Persistent poverty

Most of the world's poor — some 1.7 billion people according to the World Bank (Chen and Ravallion, 2007) — live in South Asia (SA) and Sub-Saharan Africa (SSA). Of this number, some 510 million are considered to be food insecure. For SSA, in particular, the situation is worsening, as the number of food insecure in the region nearly doubled from 125 million in 1980 to 200 million in 2000 (Molden, 2007). A key question is how to reverse this trend and improve the food security and livelihood status of these most vulnerable groups. At present about 70% of the poor live in rural areas with few immediate options for employment outside of agriculture. Thus, at least for the near to medium term, the challenge is to transform the agricultural economy from a source of poverty and food insecurity to a potential solution.

Inability to access or control water has an obvious, direct impact on potential yields. Inadequate access also has an important indirect impact by reducing the potential payoff from other productivity increasing inputs such as fertilizer, improved seed varieties, and even education. Farmers operating in this situation observe little or no growth in agricultural productivity and they are largely reliant on the vagaries of weather. Without interventions in water control, this has potentially ominous implications for poor, small-scale farmers, particularly given expectations regarding climate change. Moreover, the lack of water control influences water use for vital livelihood activities that include livestock watering, aquaculture, tree growing, small businesses, and domestic water uses, which are particularly important for women and girls.

2.8. Increasing water scarcity

Water scarcity is a critical constraint to agriculture in many parts of the world. Physical water scarcity occurs when available water resources are insufficient to meet all demands, including environmental flow requirements. Economic water scarcity occurs when investments needed to maintain pace with growing water demand are constrained by financial, human, or institutional capacity (Seckler et al., 1998). Today an estimated 1.2 billion people live in river basins characterized by physical scarcity and another 1.5 billion live in economically scarce basins (Molden et al., 2007). With increasing water demands, these numbers are expected to increase.

Limited water endowments are an obvious cause of physical water scarcity. Inadequate investments in water storage and management are typical causes of economic water scarcity. Millions of poor, small-scale farmers operate in conditions of either physical or economic water scarcity. In many arid and semi-arid areas, investments and policies are needed to improve farm-level access to irrigation water and enhance agricultural productivity. Even in some humid areas, new investments and policies are needed to ensure that water resources are allocated and used wisely across sectors, and in a sustainable manner. It is not uncommon to observe water supply limitations or "drought conditions" that result from inappropriate policies or inadequate investments, even when the natural water supply is not constraining.

2.9. Restoring ecosystems

Many authors have described the adverse impact of large-scale water diversions on ecosystems (Falkenmark et al., 2007). The index of freshwater species in the world has declined by about 50% from 1970 to 2000 (MEA, 2005). Threats to ecosystems ultimately threaten the resource base upon which agriculture depends. To reverse the trend of ecosystem degradation, several countries, such as Australia, have implemented policies to increase environmental flows, reduce agricultural pollution, and enhance the ecosystem services agriculture provides, while reducing the amount of water allocated to agriculture.

3. The Comprehensive Assessment of Water Management in Agriculture

Several authors and public officials have expressed different views regarding how to address future challenges involving food production, ecosystems, and livelihoods. For example, some emphasize developing more water through large infrastructure projects to relieve scarcity, stimulate economic growth, protect vulnerable people, and relieve pressure on the environment. Projects that transfer water from water-abundant to water-scarce basins follow this approach. At the other end of the spectrum are calls to halt the expansion of agricultural and hydraulic infrastructure, and implement practices that restore ecosystems.

Major reasons for these opposing views include different levels of awareness of fundamental information and divergent perspectives regarding the relative importance of natural and developed resources. For example, how much water is used in agriculture? How much irrigation occurs worldwide? What are the relative contributions of surface water and groundwater? What is the present use and future potential of rainfed agriculture? What type of interventions in agricultural water management is most effective in improving the livelihoods of the poor?

There is also a lack of knowledge and awareness of past impacts of agricultural water developments and the current contributions of agriculture to livelihoods, household food security, and national economic output. In addition, public perspectives regarding water resources and water allocation between competing uses vary with geography, water resource endowments, and incomes.

The Comprehensive Assessment of Water Management in Agriculture (CA), a five-year research program involving 700 policy makers and researchers from institutes, universities, and non-governmental organizations (NGOs) was designed to fill critical knowledge gaps and reconcile diverging views. CA researchers critically evaluated past experiences in water development, new challenges, and potential solutions developed by researchers and practitioners around the world. By bringing together a diverse group of people with different perspectives, the CA has made notable strides in finding common ground (Molden, 2007).

Thinking differently about water and crossing disciplinary boundaries is essential for achieving the three-part objective of ensuring food security, reducing poverty, and conserving ecosystems. Instead of a narrow focus on rivers and groundwater, we should view rain as the ultimate source of water that can be managed in irrigated and rainfed fields. Instead of blueprint designs, we need to craft appropriate governing institutions while recognizing the politically contentious nature of the reform process. And instead of isolating agriculture as a production system we need to view it as an integrated system with multiple uses and users, and as an agro-ecosystem, providing services and interacting with other ecosystems.

Future choices regarding water, agriculture, and ecosystems will involve inevitable tradeoffs. Informed multi-stakeholder negotiations are essential in reaching wise decisions regarding water use and allocation. Reconciling competing demands for water requires transparent sharing of information. Other users – fishers, small-scale farmers, households without official title to resources, and those dependent on ecosystem services – must develop a strong collective voice (Molden, 2007).

4. This special issue

The main findings and recommendations from the Comprehensive Assessment culminated in water management options related to poverty alleviation, ecosystem services, water productivity, basin and land management, rainfed and irrigated agriculture, and the use of marginal quality water. These findings are described in this special issue in nine papers based on the CA synthesis book (Molden, 2007).

In the first paper De Fraiture and Wichelns (2010) identify the drivers that will largely determine the path of expanding demand for agricultural water in the coming decades. They also examine alternative scenarios of efforts to meet future food demands, with particular emphasis on the roles of investments and policies that influence agricultural water management. The policy choices and investments made to satisfy future food demands have implications for the livelihoods of the poor and the environment. Investments in rainfed agriculture hold considerable potential but require adequate mechanisms to reduce risks. Irrigation expansion is warranted in places where water infrastructure is underinvested. The scope to improve irrigation performance and water productivity is high, particularly in South Asia. Trade can help alleviate water problems in water-scarce areas when economic and political conditions are met. In an 'optimistic scenario' as compared with 'business as usual', the amount of additional water required to meet food demand by 2050 can be reduced by 80%, thus, leaving more water for ecosystems.

Gordon et al. (2010) describe the ways in which water for agriculture influences ecosystem services provided by terrestrial and aquatic systems, both positively and adversely. Effects on aquatic ecosystems include stream flow reduction, alteration in stream flow patterns, wetland degradation and declining water quality. Terrestrial ecosystems are affected through changes in groundwater levels and alterations to runoff due to land use changes. Better agricultural water management can play a key role in mitigating the negative effects. First, there are large opportunities to improve management practices to increase water productivity, reduce water use and minimize pollution. Second, improved water management in upstream food production areas can mitigate adverse impacts downstream, while unavoidable tradeoffs can be negotiated (e.g., through payments for ecosystem services). Lastly, water managed to create multi-functional agro-ecosystems can increase synergies between different ecosystem services, in addition to agricultural production. The provision of multiple ecosystem services is often crucial to ensuring sustainable livelihoods for poor people.

Agriculture, natural resources, and ecosystem services are intimately linked with livelihoods, food security, and poverty reduction. Access to reliable water improves crop and livestock production, enhances employment opportunities, and stabilizes income and consumption. It also encourages the use of other yield-enhancing inputs and allows diversification into high-value products, enhances non-farm outputs and employment, and fulfils the multiple needs of households. Namara et al. (2010) argue that poverty reduction strategies should include four elements: (1) ensuring secure rights of access to water for the poor, through water rights and investments in water storage and delivery infrastructure where needed; (2) empowering people to use water more effectively; (3) improving the governance of water resources; and (4) supporting the diversification of livelihoods. Multiple-use systems – operated for domestic use, crop production, aquaculture, agroforestry, and livestock – can reduce poverty, while improving land and water productivity.

Some of the goals of improving land and water productivity include producing more food, generating greater income, enhancing livelihoods, and providing more ecosystem services–while using less water. Molden et al. (2010) show there is considerable scope for improving crop water productivity through water harvesting, supplemental irrigation, deficit irrigation, precision irrigation techniques, and soil-water conservation practices. There is also great scope for improving economic water productivity by increasing the values generated by water use and reducing associated costs.

However, there are several reasons to be cautious about the scope and ease of increasing crop water productivity. First, crop water productivity is already quite high in highly productive regions. Second, re-use and recycling of water already may be high, and perceived losses and inefficiencies might be lower than generally assumed. Third, while improvements in crop genetics have notably enhanced water productivity in the past, such large gains are not easily foreseen in future. Lastly, the enabling conditions for farmers and water managers to enhance water productivity are not in place. Priority areas for improving water productivity include areas where water is scarce, yields are low, and poverty is prevalent.

Bossio et al. (2010) argue that the key to effective water resources management is the understanding that the water cycle and land management are inextricably linked. Gains in agricultural water productivity will be obtained only in conjunction with improvements in land use management. A global survey suggests that 40% of agricultural land is already degraded to the point that yields are greatly reduced, and a further 9% is degraded to the point that it cannot be reclaimed for productive use through farm-level measures. Soil erosion, nutrient depletion, and other forms of land degradation reduce water productivity and affect water availability, quality, and storage. Reversing these trends will require tackling the underlying social, economic, political, and institutional drivers of unsustainable land use. Options to reduce land degradation include focusing on small-scale agriculture, investing in rehabilitating degraded land to increase water productivity, and enhancing the multi-functionality of agricultural landscapes.

Upgrading rainfed agriculture through better rainwater management holds considerable scope for poverty alleviation and increased food production, while minimizing additional water use. Rockström et al. (2010) identify semi-arid and dry sub-humid savannah and steppe regions with water related constraints to food production, high prevalence of undernourishment and poverty, and rapidly growing food demands as high priority areas for investment. In those regions rainfed agricultural and water productivities are low, due partly to lack of water, and also to inefficient management of water, soils, and crops. Yield gaps are large, with actual yields generally only a portion of achievable yields for major food crops. Targeted interventions could double yields, but this will require a broadening of the scope of policies and perceptions of agricultural water management to include rainwater, in addition to water in rivers and aquifers.

While the role of rainfed agriculture likely will increase in importance, the contribution of irrigated agriculture will remain fundamental to food supply and livelihoods. Turral et al. (2010) conclude that the days of rapid expansion in irrigated area are over, although growth is needed in areas with abundant water resources and little infrastructure, such as parts of Sub-Saharan Africa. A major new task is adapting yesterday's irrigation systems to tomorrow's needs. Modernization, a mix of technological and managerial upgrades 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. There are compelling reasons to continue to invest in irrigation: to preserve the existing stock of irrigation infrastructure and the value of that investment; to assist the rural poor in gaining livelihoods that move them out of poverty; to adapt to and satisfy the changing food preferences of increasingly wealthy urban and rural populations; to improve irrigation performance; to adapt to the impacts of climate change; and to productively, safely and cheaply re-use the increasing volumes of urban wastewater that will be generated in the future.

Qadir et al. (2010) note how the productive use of wastewater has increased with increasing urbanization. Millions of small-scale farmers in urban and peri-urban areas of developing countries depend on wastewater or wastewater-polluted water sources to irrigate high-value, edible crops for urban markets. Often the farmers have no alternative sources of irrigation water. Undesirable constituents in wastewater can harm human health and the environment. For numerous reasons, many developing countries are still unable to implement comprehensive wastewater treatment programs. Therefore in the near term, risk management and interim solutions are needed to prevent adverse impacts from wastewater irrigation. A combination of source control, and farm-level and post-harvest measures can be used to protect farm workers and consumers. Furthermore, there are several opportunities for improving wastewater management through improved policies, institutional dialogues, and financial mechanisms, which would reduce the risks in agriculture.

Water basins are considered to be "closing" when the supply of water falls short of commitments to fulfill demands in terms of water quality and quantity, within the basin and at the river's mouth, for part or all of the year. Molle et al. (2010) describe basin closure as an anthropogenic process manifested at societal and ecosystem levels. With basin closure, the interconnectedness of the water cycle, aquatic ecosystems, and water users increases greatly. Local interventions such as tapping more groundwater, lining canals, or using micro-irrigation often have third-party impacts and unexpected consequences elsewhere in the basin. Political choices need to be made to initiate a transition toward more balanced practices, with more attention given to tradeoffs, and with a view toward sustaining ecosystems and ensuring equity. Where poverty is widespread, strategies for river basin management should include, at a minimum, mechanisms for addressing imbalances in water access and establishing recognized and secure water entitlements for the poor.

5. Concluding remarks

The Comprehensive Assessment has identified a clear need for investments in agricultural water management. The best types of investments and optimal implementation plans will vary across water basins and regions. In most situations, efforts to improve water management and increase agricultural productivity will require difficult choices involving tradeoffs that might include:

(1) *Providing water storage for agriculture—ensuring water for the environment*. The Comprehensive Assessment describes the need for more storage of water including, as locally appropriate, reservoirs behind large and small dams, groundwater recharge and storage, and water harvesting – albeit at a slower rate than in the past. The strategy of increasing water storage will be implemented in many regions, partly as a precaution against changes in rainfall patterns due to climate change. This strategy, while optimal from a water supply perspective, will decrease instream flows in some rivers for some period of time.
(2) *Reallocation—over-allocation*. Providing access to water and safeguarding water rights have been identified as key poverty concerns. In many "closed" basins, water resources are already over-allocated, making allocation decisions particularly difficult. New allocations of water in closed basins will require re-negotiating existing water allocations. Key questions in this process will include who will benefit the most from increases in water allocations, and how will gainers compensate the losers.
(3) *Upstream–downstream.* Economic development in the upstream reaches of river basins often has impacts on freshwater fisheries, environmental flows, and coastal areas in lower portions of the basins. Often economic development projects are implemented without discussing them with those who might be impacted. Discussions regarding upstream developments, downstream impacts, and potential compensation programs often are complicated due to cause and effect relationships that are difficult to identify and property rights

that are not clearly defined. Inadequate property rights, unequal social status, and too little political influence often leave poor farmers and poor fishers unable to retain access to water when upstream developments reduce flows to downstream areas.

(4) *Equity—productivity.* Investments that promote productive and efficient agriculture tend to favour the wealthy, while investments and policies that promote more equitable agriculture are not necessarily productive.

(5) *This generation—the next ones.* Some choices made now will impose benefits and costs on future generations. For example, with groundwater levels dropping in many areas, mining the groundwater further today will reduce the volume available in future. Hence, investments and policies pertaining to groundwater use must account for the long-term "scarcity cost" that users today impose on future generations. The optimal investments and policies will ensure that the incremental benefits of groundwater use today are sufficient to cover today's pumping costs, plus the cost of having less groundwater available in future. This perspective is consistent with the notion of developing groundwater resources in a sustainable manner, rather than supporting economic development today, with no plan for maintaining economic activity and supporting livelihoods in future.

The challenges inherent in each of these tradeoffs will become more pronounced with rapidly increasing food demands, rising food prices, increasing water scarcity, and the uncertainties of climate change. The sense of urgency for addressing many of these tradeoffs will increase in future, as more river basins reach closure, and the competition for available land and water resources intensifies. The Comprehensive Assessment has endeavored to look ahead at these inevitable tradeoffs and to offer an informed perspective of the likelihood that future goals can be achieved with the world's existing water resources. The nine chapters in the special edition summarize the primary findings of the Comprehensive Assessment and describe the policies and investments needed to continue improving agricultural productivity, while also reducing poverty, improving livelihoods, and supporting ecosystems during the next 50 years. We are hopeful that the findings of the Comprehensive Assessment and the summaries provided here will generate helpful discussion among agricultural and water professionals regarding the most appropriate strategies for achieving these critically important goals.

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