Challenges and Policies for Global Water and Food Security

By Mark W. Rosegrant

Water is essential for growing food; for household uses including drinking, cooking, and sanitation; as a critical input into industry, for tourism and cultural purposes; and in sustaining the earth's ecosystems. But this essential resource is under threat. Growing water scarcity in much of the world poses challenges for national and subnational governments and for individual water users. The challenges of water scarcity are compounded by soil degradation in irrigated areas, the increasing costs of developing new water, overpumping and depletion of groundwater, water pollution and degradation of water-related ecosystems, and the wasteful use of already developed supplies encouraged by subsidies and distorted incentives that influence water use (Rosegrant).

Growing water scarcity and water quality constraints are a major challenge to future food security, especially since agriculture is expected to remain the largest user of freshwater resources in all regions of the world for the foreseeable future despite rapidly growing industrial and domestic demand. As non-agricultural demand for water increases, water will be increasingly transferred from irrigation to other uses in many regions. In addition, the reliability of the agricultural water supply will decline without significant improvements in water management

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policies and investments. The intensifying sectoral competition and water scarcity problems, along with the declining reliability of agricultural water supply, will put downward pressure on food supplies and continue to generate concerns for global food security.

Ringler and others project future water stress, showing that in 2010, 36 percent of the global population—approximately 2.4 billion people—live in water-scarce regions. In addition, 22 percent of the world's gross domestic product (GDP)—$9.4 trillion at 2000 prices—is produced in water-short areas (Figure 1). Moreover, 39 percent of global grain production is in water-stressed regions. In China, India, and many other rapidly developing countries, water scarcity has already started to materially risk growth—in these two countries alone, 1.4 billion people live in areas of high water stress today.

Business-as-usual (BAU) levels of water productivity under a medium economic growth scenario will not be sufficient to reduce risks and ensure sustainability. Under BAU, 52 percent of the global population (4.7 billion people), 49 percent of global grain production, and 45 percent ($63 trillion) of total GDP will be at risk due to water stress by 2050 (Figure 1). These risks will likely influence investment decisions, increase operation costs, and affect the agricultural competitiveness of certain regions (Ringler and others).

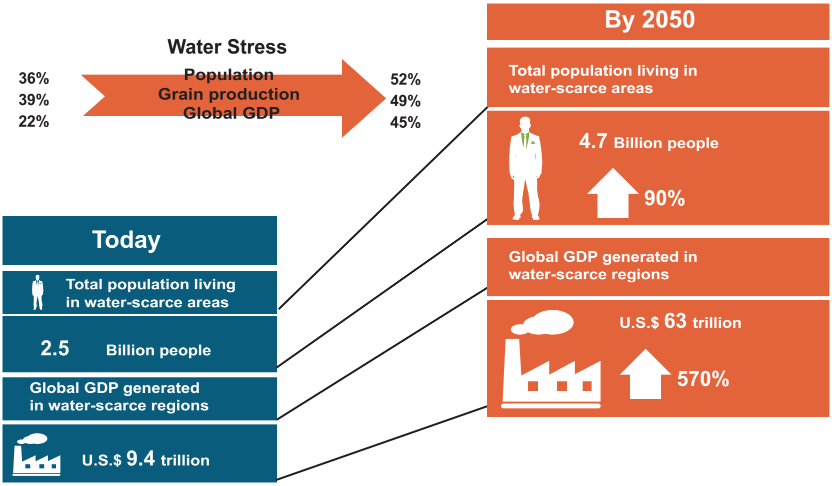
Section I summarizes projections for BAU outcomes for food security, showing that under the BAU scenario, increasing water scarcity and other factors are projected to slow agricultural growth and raise food prices. Section II provides evidence on the effect of water scarcity on economic growth, and Section III summarizes the relationship between climate change and water resources. Section IV deals with the policies, management, and technologies and investments that can lead to a better future for water and food security. Section V examines an alternative scenario to see whether plausible increases in water and crop productivity can provide significantly better outcomes for water and food security.

I. Water and Food Security

With declining water availability and limited land that can be profitably cultivated, expansion in area will contribute very little to future production growth. Slow growth in investment in agricultural research,

Figure 1

Projected Water Stress to 2050 under Business-as-Usual Scenario



Source: Author based on Ringler and others.

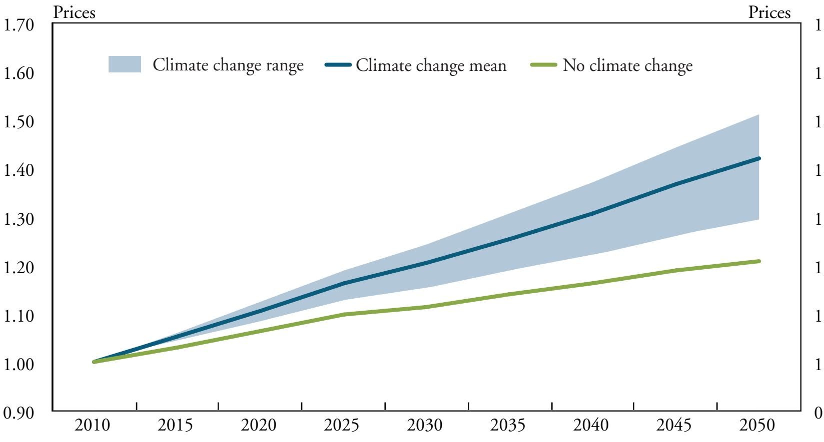
irrigation, and rural infrastructure in developing countries is likely to dampen productivity growth; climate change will reduce the rate of productivity growth as well. These supply factors, coupled with growing population (mainly in Africa and South Asia) and rising income, are projected to raise food prices and slow improvements in food security under BAU conditions, as shown in Charts 1 and 2. International prices of grains are projected to increase by 20 percent even without climate change. With climate change, across a range of general circulation models, the mean price increase from 2010 to 2050 is projected to be approximately 50 percent. Meat prices are projected to increase by 20 percent as well, with a slight decline in prices after 2040 as developed countries, China, and Brazil reduce their per capita meat consumption (Chart 1).

Other food prices are projected to increase in the range of 10–30 percent. These higher food prices also lead to slow reductions in hunger. Although Chart 2 shows projected reductions in the population at risk of hunger both with and without climate change, these reductions are far smaller than the targets in the United Nations Sustainable Development Goals, which call for ending hunger in 2030. With climate change, even by 2050, 155 million people are projected to be at risk of hunger in sub-Saharan Africa, 140 million in South Asia, and 530 million across the developing regions.

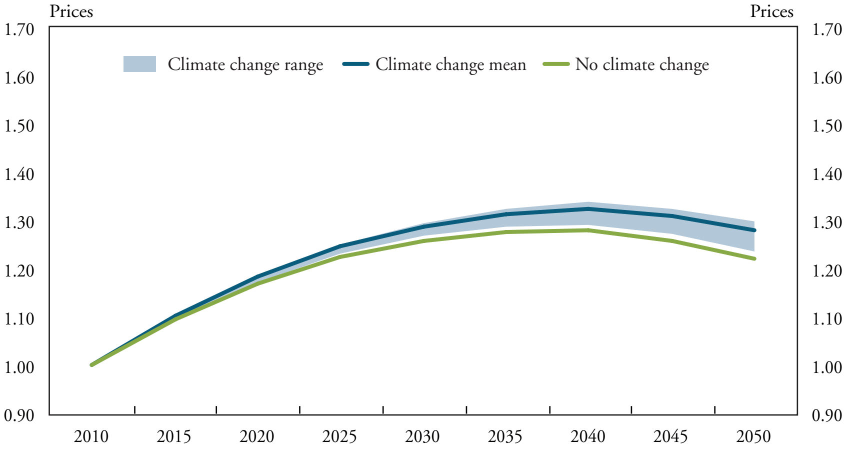
Chart 1

Projected Prices of Grains and Meats

Panel A: Grains



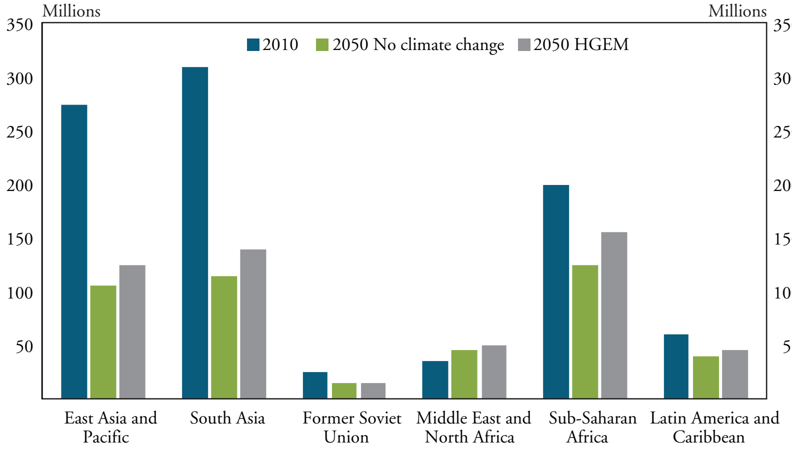
Panel B: Meats



Note: Real prices indexed to 2010 with and without climate change.
Source: Author from IMPACT results.

Chart 2

Projected Population at Risk of Hunger in 2050



Note: Chart shows projected population at risk of hunger in 2050 with and without climate change, using shared socioeconomic pathways 2 and representative concentration pathway 8.5.
Source: Author from IMPACT results.

II. Water and Economic Growth

In addition to their effects on agriculture and food security, water scarcity and water-related investments can increase economic productivity and growth. Sadoff and others summarize much of the evidence for this relationship. They conclude that the connection between water security and economic growth is intuitively clear, but that the empirical evidence of this relationship is scarce. More recent econometric analyses have considered variability in precipitation in addition to mean levels. Brown and others (2011), cited in Sadoff and others, show that rainfall variability, floods, and droughts have a statistically significant negative and detrimental effect on different measures of economic growth in sub-Saharan Africa. Brown and others (2013) find that anomalously low or high precipitation has a negative economic effect, thereby providing evidence that variability in precipitation can hinder growth.

Using an econometric model, Sadoff and others show that runoff has a statistically significant positive relationship with growth, indicating that greater water availability has a significant and positive causal effect on economic growth. Drought is shown to have a statistically significant negative effect on economic growth as well. On average, a major drought (affecting 50 percent or more of a country's area) is found to reduce economic growth (as measured by per capita GDP) by about half a percentage point in that year. Flood extent likewise has a negative effect on per capita GDP growth. Simulations that determine the benefits of reduced drought demonstrate that the effect of droughts may compound over a long time period. Sadoff and others also find that the effects of hydro-climatic variables on growth are strongest in poor countries and countries with high human water stress, high dependence on agriculture, or both.

The World Bank (2016) simulates the effect of water on economic growth using a Computable General Equilibrium (CGE) model that captures how changes in the water sector affect the rest of the economy. The economic consequences are highly unequal, with the worst effects in the driest regions. The expected global damage is small relative to expected global GDP in 2050. But global damage is a highly misleading estimate, because significant variations exist between regions. Western Europe and North America, where much global GDP is produced, experience negligible damage in most scenarios. The bulk of losses are in the Middle East, the Sahel, and Central and East Asia, and the magnitude of the losses is largely driven by the water deficit. Specifically, the GDP loss in 2050 under a water-constrained scenario amounts to −7 percent in East Asia, −7 percent in Central Africa, −11 percent in Central Asia, −11 percent in Sahel, and −14 percent in Middle East (World Bank 2016).

Economic feedback effects and adjustments can limit the damage from water shortfalls. Apart from the direct effect of water shortages on yields and crop areas, macroeconomic outcomes are similarly affected by prices and international trade. Liu and others, also using a CGE model, find that even countries experiencing negative output shocks due to reduced irrigation availability may gain from the higher commodity prices caused by the shocks. Regions can take advantage of trade to adjust the composition of agricultural income and specialize in more beneficial commodities. These adjustment effects, which are mediated by markets, reduce the initial effect of reduced water availability in farming.

III. Effects of Climate Change on Water

Climate change is projected to substantially change mean annual streamflows, the seasonal distributions of flows, the melting of snowpack, and the probability of extreme high- or low-flow conditions. The effects of climate change on water resources include changes in the timing of water availability due to changes in glaciers, snow, and rainfall; changes in water demands due to increased temperatures; changes in surface water availability and groundwater storage; an increased number and intensity of extreme climatic events (droughts and floods); changes in water quality; and sea-level rise (Rosegrant, Ringler, and Zhu). World Bank (2010) shows that most regions will experience more intense and variable precipitation, often with longer dry periods in between (Burke and Brown; Burke, Brown, and Christidis). The effects on human activity and natural systems will be widespread.

The ultimate outcome of climate change and its effects on water availability is difficult to project. Unknowns include geographic location, direction of change (less or more precipitation), degree of change in precipitation (low or high), change in precipitation intensity (low or high), and timing (within the next five years or over multiple decades). Shifting precipitation patterns and warming temperatures could increase water scarcity in some regions, while other areas may experience increased soil-moisture availability that could increase opportunities for agricultural production (Malcolm and others). But as the World Bank (2010) notes, these uncertain changes will certainly make it harder to manage the world's water. In addition, people will feel many of the effects of climate change through water. Climate change will make flexible water allocation more important to adjust to extreme events and changes in the timing of water availability, water demands, and surface water availability.

IV. Water Policies and Investments

Meeting the challenges of climate change and water availability will require action on many fronts. This section summarizes critical priorities to enhance water use efficiency and productivity.

Investing in crop breeding for yield per unit of water and land

The first step to better water use productivity is not directly part of the water sector: productivity gains for both irrigated and rainfed agriculture. Cai and Rosegrant find that while both increases in crop yield and improvements in basin efficiency contribute to increases in water productivity (crop yield per meter of applied water), the larger contribution comes from increases in the crop yield. Moreover, improvements in rainfed crop yield per hectare and unit of water would reduce pressure on irrigated crops. Plant breeding can improve plant biomass per unit of water through transpiration rates and can improve the efficiency of biomass growth per unit of transpiration. Although improvement in crop yield per unit of water use is a challenging breeding goal, it continues and has further potential (Richards and others 1993; Richards and others 2002; Ortiz and others). Diverse genes are essential for effective breeding for drought tolerance and other traits to get more yield per unit of water. To support a broad and targeted gene pool, the tools of biotechnology should be employed, including marker-assisted selection, cell and tissue culture, and gene editing, even if countries elect to forego transgenic breeding (Morison and others; Christensen and Feldmann).

Adopting new irrigation technologies and farming systems

Improved irrigation technologies, such as drip and sprinkler irrigation; and crop and water management, such as enhanced water harvesting, conservation tillage, and precision farming that optimizes application of water and other inputs within the field; can improve yields and enhance rural and farm incomes. However, because of the interconnected nature of water supplies, with runoff from one water user often being available to other users through return flows, different outcomes are possible when a new technology is put in place. For example, new technology can save water that would otherwise evaporate unproductively, providing net system benefits; divert water that would otherwise be used downstream by others, shifting benefits between farmers, rather than generating new benefits; or induce increased water use by increasing the profitability of irrigation for individual farmers rather than saving water (World Bank 2010). Farmers have many reasons to adopt advanced irrigation technologies, including increased income from higher value crops, convenience, labor-saving, and lower pumping costs; however, real water savings are more difficult to achieve and often limited (Perry and others).

The potential benefits of new technologies and farming systems are promoted by a water allocation system that recognizes these hydrological realities. Well-specified water rights and allocations have the potential to significantly improve water and food security and tap the potential gains of new technologies.

Establishing water rights and water trading

Water rights are the cornerstone of efficient and equitable water management. Secure and well-defined water rights provide incentives for investment in more efficient technology; making those water rights tradable provides additional incentives to optimize the economic value of water. Moreover, a properly managed system of tradable water rights provides incentives for water users to internalize the external costs imposed by their water use, reducing the pressure to degrade resources (Easter and Huang; Rosegrant and Binswanger). Young lays out a blueprint for establishing water rights and trading based in significant part on the experience in the Murray Darling River Basin in Australia. The conditions for effective water rights should include a perpetual right to a proportion (share) of all allocations made in the river basin or system. The actual allocation made in any season should be specified as a share of the total water available determined in a transparent process and accounting for system evaporative losses and environmental outcomes, including water quality and flows to the sea (Young; Young and McColl).

Establishing water rights that create incentives for efficient water use as well as trading systems to optimize economic returns has proven very difficult even in developed countries. In developing countries, the high costs of measuring and monitoring water use where infrastructure and institutions are weak and irrigation systems are often large and service many small farmers can also be a major constraint to implementing water rights and trading. Adding to the difficulty of reform, both long-standing practices and cultural and religious beliefs have treated water as a free good, and entrenched interests benefit from the existing system of subsidies and administered allocations of water (Rosegrant, Ringler, and Zhu 2009). Well-defined water rights and trading in developing countries would be enhanced by improved irrigation technology for conveyance, diversion, and metering; institutional improvement in the management of irrigation systems; and in many cases, community organizations to manage water allocation. Developing well-specified water rights and trading is likely to be a medium- to long-term process in most developing countries. An initial focus on realistic allocation of water on a seasonal basis—along with registration of rights based on shares—would be a major first step.

Groundwater use in much of the world has increased very rapidly in a short period of time, particularly in Asia, where cheap pumps are available and energy and water are often subsidized. While expanding groundwater use has been highly beneficial, overdrafting is excessive in many instances, causing land subsidence, salinization, and other degradation of land and water quality in the aquifer. The principles of groundwater management through water rights and trading are essentially the same as described above, but are even more complex than surface systems due to the invisibility of the resource, the lack of data on safe yield or availability, and groundwater movement. Elements of successful groundwater management include recognized user rights, monitoring processes, means for sanctioning violations, and procedures for adapting to changing conditions. Again, institutional capabilities to establish such systems are lacking in most developing countries, but measuring groundwater and establishing clear rights would be an important step forward.

Capital investment in irrigation and water

Because new investments in irrigation and water supply are increasingly expensive and politically sensitive, hard infrastructure investment has a reduced role globally compared with past decades, when dam-building and expansion of irrigated area drove rapid increases in irrigated area and crop yields, particularly in developing countries (Rosegrant, Ringler, and Zhu). Still, some regions of the world have substantial potential for irrigation expansion. The World Bank's Africa Infrastructure Country Diagnostic (AICD) study concludes that Africa has the potential to add at least 16 million hectares of profitable large-scale irrigation (You and others). Xie and others show an even greater potential for profitable smallholder irrigation expansion in sub-Saharan Africa: the authors identify area expansion potential up to 30 million hectares for motor pumps, 24 million hectares for treadle pumps, 22 million hectares for small reservoirs, and 20 million hectares for communal river diversions. The technologies can benefit between 113 million and 369 million rural people in the region, generating net revenues of $14–22 billion depending on technology.

Finally, large additional investments in water treatment and sewage disposal plants will be required. Various estimates exist for the necessary investments to improve sanitation standards, especially in the developing world. In a study commissioned by the World Health Organization, Hutton and Haller estimate that access to improved water and sanitation services for all would cost around $22.6 billion per year, and access to both regulated, in-house piped water supply with quality monitoring and in-house sewerage connection with partial treatment of sewage would require a total investment of $136.5 billion per year.

V. The Effects of Improved Water Use Efficiency and Productivity

Can implementing the measures described above significantly improve water and food security compared with the outcomes in the BAU scenario? Rosegrant and others (2013) simulate an alternative scenario for water and food security that combines water use efficiencies in the domestic, industrial, and irrigation sectors to reflect direct water-saving effects, higher crop productivity growth per unit of water consumed, and the resultant higher GDP growth stimulated by higher agricultural productivity. The authors use the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): a partial equilibrium, multicommodity, multicountry model that generates projections of global food supply, demand, trade, and prices as well as water supply and demand (see Rosegrant and others 2012 for a detailed description of IMPACT). The CGE model GTEM is used iteratively with the IMPACT to generate the multiplier effects from agricultural and water sector productivity growth to GDP growth (Ahammad and Mi). The efficiency gains for industrial and residential water use are taken from the WaterGAP model (Ozkaynak and others). The underlying drivers for water use efficiency gains, as described in the Global Environment Outlook V (GEO5) report, include stringent efficiency measures taken in industry and residential water use. They also include climate policies that lead to reduced demand for thermal cooling in power generation, as fossil-fuel-powered plants are partly replaced by renewable energy sources. For agriculture, Rosegrant and others (2013) estimate the basin water use efficiency gains based on more efficient transpiration (including drought resistant varieties and other advances in research as described above), reduced non-beneficial evapotranspiration (ET), and reduced losses to water sinks (for example, due to water-conserving irrigation and crop management technologies and reduced evaporative losses during conveyance). The average efficiency gains for global, basin-level water use are 8.8 percent by 2030 and 14.5 percent by 2050 compared with the BAU scenario (Rosegrant and others 2013).

The simulated improvements in efficiency result in an improvement in irrigation water supply reliability (IWSR), defined as the annual ratio of irrigation water supply to demand. The degree of improvement varies by country and regions, but globally, IWSR is 0.619 under the BAU scenario and 0.726 under the higher efficiency and productivity scenario. This improvement results in higher reliability than in the 2000 base year while accommodating significant increases in irrigated area (Rosegrant and others 2013).

With higher crop yield growth and larger crop production under the more efficient scenario, prices for most crops, including rice, wheat, maize, and oils decline relative to the BAU scenario despite the higher income growth generated under the more productive scenario. Price declines are generally in the range of 10–20 percent in 2050 compared with the baseline. Prices for meat, fruits, and vegetables increase slightly, reflecting the effect of higher income on these commodity markets. Per capita food demand increases as a result of higher income growth and lower agricultural commodity prices.

Rosegrant and others (2013) also project the number of people facing the risk of hunger in the different regions of the world. With higher water and productivity growth expanding the food supply and pushing down food prices, and with improving GDP growth to boost per capita food consumption, fewer people will be at risk of hunger. In the projected alternative scenario, the number of people at risk of hunger declines significantly for all developing regions. The two regions with the most severe hunger issues gain the most sub-Saharan Africa has the biggest percentage drop in hunger, with a 44 percent reduction in the population at risk of hunger in 2050 compared with BAU, reducing the number of hungry people by 66 million in 2050 relative to BAU.

VI. Conclusions

Water scarcity is projected to increase in much of the world, and together with climate change and other factors will likely slow growth in agricultural productivity and slow progress in the reduction of hunger. But a plausible scenario for water and crop productivity growth—predicated on a set of water allocation reforms, new water technologies and farming systems, investment in crop research to increase yield with respect to water, and selective new investment in irrigation and water sanitation and sewage—can significantly improve water and food security outcomes. The precise mix of water policy and management reform and investments—and the feasible institutional arrangements and policy instruments used to achieve them—must be tailored to specific countries and basins and will vary across underlying conditions and regions, including levels of development, agroclimatic conditions, relative water scarcity, level of agricultural intensification, and degree of competition for water. These solutions are not easy, and they will take time, political commitment, and money.

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