Global Water and Food Security:
Emerging Issues

Mark W. Rosegrant
Sarah A. Cline
Rowena Valmonte-Santos

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MARK W. ROSEGRANT, SARAH A. CLINE AND
ROWENA ANDREA VALMONTE-SANTOS

Environment and Production Technology Division
International Food Policy Research Institute
2033 K Street, NW, Washington, DC 20006
Email: m.rosegrant@cgiar.org

Feeding the world's population is an ongoing challenge that incorporates issues such as economic growth and equity, sustainable natural resource management, agricultural research and technology innovation, and effective institutions and governance. Many emerging factors will affect our ability to address this challenge into the future, as we respond to population growth, resource degradation and scarcity, climate change and so on. To a large extent, agricultural production growth will depend on irrigation, but the future of irrigation water supplies is increasingly constrained by competition for water from other sectors. Declining water quality, falling groundwater tables, and growing environmental demands for water are further constraints, and globalisation and trade liberalisation will continue to introduce new variables.

MARK W. ROSEGRANT is Director, Environment and Production Technology Division, International Food Policy Research Institute (IFPRI). A PhD in Public Policy from the University of Michigan, he has 28 years of experience in research and policy analysis in agriculture and economic development, with an emphasis on water resources and other critical natural resource and agricultural policy issues as they affect food security, rural livelihoods and environmental sustainability. Rosegrant developed IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which has become a standard for projecting global and regional food demand, supply, trade and prices; and IMPACT-WATER, which integrates a detailed water supply and demand model with the food model. His current research includes bioenergy and climate change effects on agriculture and adaptation policies. He is the author or editor of six books and over 100 refereed papers in agricultural economics, water resources and food policy analysis.

This paper focuses on three emerging factors that will strongly affect water management and agricultural production. We describe them as the 'new ABCs' of future water and food security: aquaculture, biotechnology and climate. In particular, these factors will have a major effect on agricultural water use around the world. Successfully meeting both new and existing water and food security challenges necessitates fundamental changes in water management, driven by sound government policy. Ultimately, this requires appropriate financial investments, research, water-management reform and effective economic incentives.

Introduction

To a large extent future food production will depend on irrigation, but with increasing demand from other sectors, the availability of water for food production is likely to be significantly reduced. In addition, many other challenges threaten the provision of water for food production and, ultimately, the food security of many people around the world. Assessing the current and future situation for water and food production is crucial for understanding the potential impacts of the challenges outlined above. The International Food Policy Research Institute (IFPRI) undertakes such analyses using the model it developed for this purpose — the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which in recent years has incorporated issues related to water, resulting in the model IMPACT–WATER (Rosegrant *et al.* 2002)[1].

Globally, cereal demand is projected to increase by 828 million metric tonnes (mmt) by 2025, with the great majority occurring in developing countries (712 mmt), where consumer preferences are expected to shift from maize and other coarse grains towards wheat and rice, with greater per capita consumption of fruit, vegetables and meat as well. Meat demand is also projected to increase rapidly by 2025 (138 mmt globally), again predominantly in developing countries (119 mmt). China makes up a large portion of this increase (39%), which also fuels the above-mentioned increase in cereal demand because more feed is required for the increased livestock production.

Productivity growth is fundamental to meeting these increasing levels of demand, but projections indicate that future growth in cereal yields will decline across nearly all regions. Water scarcity is responsible for a significant amount of this decline in developing countries, where food security will continue to be a problem. And while some regions are set to make progress in combating childhood malnutrition, millions of children will still suffer from malnutrition in 2025, particularly in South Asia and Sub-Saharan Africa.

Irrigation plays a particularly large role in agricultural production in developing countries, where it is projected to account for 57% of the growth in cereal production between 1995 and 2025, and 80% of the growth in global irrigated cereal production between 1995 and 2025 (Rosegrant *et al.* 2002). Nevertheless, added constraints will continue to be placed on irrigation water supplies as non-agricultural demand for water rises at much faster rates than water demand for irrigation — though total water consumption for non-irrigation uses will still be much lower than consumption for irrigation (Fig. 1). Several other factors will also affect the availability of water for agricultural production, including unsustainable groundwater use, environmental demands for water and water quality problems.

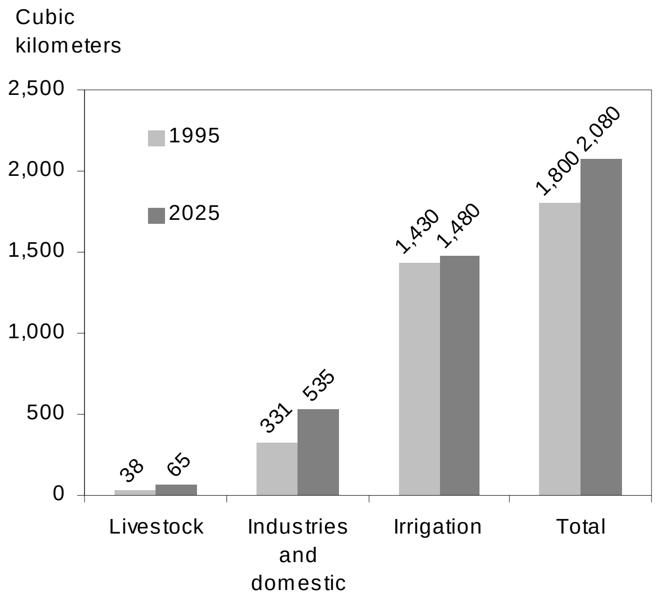

Figure 1. Water consumption by different sectors, 1995 and 2025 (baseline scenario). Source: Rosegrant *et al.* (2002).

The ABCs of future water and food security

With advances in agricultural science and technology come crucial issues regarding natural resource management, the environment, infrastructure, institutions and governance. These concerns are particularly important in addressing income equity, resource accessibility, and water and food availability for poor farmers and fishers in developing countries. This paper focuses on three emerging factors — termed ‘the ABCs’ of future water and food security — that will significantly affect agricultural productivity: aquaculture, biotechnology and climate.

Aquaculture

Aquaculture — the fastest-growing segment of animal food production — involves the reproduction, breeding, cultivation and marketing of aquatic plants and animals in a controlled or semi-controlled environment (FAO 2004; Rosegrant *et al.* 2004). Land-based aquaculture involves ponds, fish tanks, irrigation canals, dams and crop areas using freshwater or seawater-holding tanks, while water-based aquaculture occurs within rivers, lakes, coastal areas, oceans and high seas using pens and cages. Two essential factors in aquaculture production are water quality and water availability.

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[1] For a full description of the model, see Rosegrant *et al.* (2002).

In 2003, recorded fish production was 132.2 mmt globally (FAO 2004); capture fisheries constituted over two-thirds of this amount, while aquaculture provided the remainder. IFPRI IMPACT projections (Rosegrant *et al.* 2004) indicate that by 2020 these shares will have reversed, largely due to growth in aquaculture in Asia, especially in China (Table 1). This growth will be an important factor for the food security and nutrition of poor people in Asia and elsewhere, while at the same time significantly contributing to developing-country economies.

Aquaculture, however, can have detrimental effects on water quality, water quantity, biodiversity and the health of ecosystems, all of which can add pressure to capture fisheries. The predicted — extraordinarily rapid — growth of aquaculture into the future could add substantial stress to freshwater ecosystems. Fish culture operations, especially in intensive aquaculture, use fertilisers for pond preparation and require large quantities of fishmeal or fish feed as fish food. Resulting excess quantities of nitrates and phosphates lead to a water condition called eutrophication, triggering intense growth of aquatic plants, clogging waterways, depleting them of oxygen, and hindering light penetration into deep water. As aquatic plants decompose, bacteria deplete the water of dissolved oxygen, causing fish kills.

Aquaculture also exacerbates water loss through pond seepage, evaporation and production intensity. Because fish ponds are generally constructed on clay soils, associated water leakage is generally more pronounced than leakage from crops. Total water use for channel catfish culture ranges from 225 to 252 m^3 for a 1-ha pond over one year in humid to arid climates. From this volume, consumptive water use varies from 130 to 234 m^3, while pond seepage is estimated to be around 108 $m^3\ ha^{-1}$ of pond surface per year (Boyd 2005). Given these statistics, proper management practices are imperative if excessive water losses are to be avoided. Further research is also needed to quantify the consumptive use of water by aquaculture and the degree to which it will compete with other water demand in the future.

Table 1. Projected world fish production, 1973, 1997 and 2020 (baseline scenario)

Region/country	Fish production (million metric tonnes)		
	1973	1997	2020
China	10	36	41
Other developing countries	33	37	38
Japan	17	6	4
European Union (15 countries)	13	6	5
Developed countries (all)	56	27	21

Source: Rosegrant *et al.* (2004)

Biotechnology

Agricultural biotechnology has the potential to provide powerful tools for the sustainable development of agriculture, fisheries and forestry to meet the world's growing food and nutrition needs and support the development of sound economies. Biotechnology can contribute in a variety of areas. Its impact on future irrigation needs — and thereby the need for irrigation infrastructure and investment — could be profound. Environmental stresses that adversely affect agricultural productivity, such as drought, salinity, soil infertility and groundwater contamination, can also be addressed through the application of biotechnologies (World Water Vision 1999; FAO 2000; USERC 2005). Genetic engineering has significant potential for increasing productivity, while at the same time improving nutrition. Rice, for example, has been engineered to contain pro-vitamin A (beta carotene) and iron (FAO 2000; Hossain *et al.* 2004).

Biotechnology is also contributing to water quality and waste water management. To date it has played a key role in removing organic solids, like human waste, from millions of litres of wastewater generated daily (World Water Vision 1999) through the use of bio-remediation (the use of living organisms to reduce or eliminate environmental hazards resulting from accumulations of toxic chemicals or other hazardous wastes). Biotechnology has the potential to supply new methods for feasibly purifying otherwise untreatable water as well as decreasing the need for and cost of water purification, to offer integrated technology options that replace chemical options, and to develop tools to facilitate the reclamation of degraded land (World Water Vision 1999).

Despite these broad prospects, the use of biotechnology is controversial, and public acceptance and safety issues must be resolved. There are four main categories of potential risks associated with biotechnology: (a) effects on human and animal health, (b) environmental consequences, (c) ethical concerns, and (d) socioeconomic issues (Hossain *et al.* 2004). The risks of transferring toxins from one life form to another, creating new toxins or transferring allergic compounds from one species to another could lead to unexpected allergic reactions, with hazardous human health impacts. Environmental risks include the possibility of outcrossing, such as the development of aggressive weeds or wild relatives with increased resistance to diseases, or the rapid creation of new pest biotypes through adaptation to genetically modified plants, upsetting the ecosystem balance. In addition, biodiversity may be lost due to displacement of traditional cultivars by a small number of genetically modified cultivars (FAO 2000). Scientists are designing ways to minimise the potential risks associated with biotechnology and generate information for consumers about the negative side effects before recommending their release to farmers for adoption. Most Asian governments have begun setting regulations to enact biosafety policies (Hossain *et al.* 2004).

Financial investment in agricultural research is fundamental to the continuous application of both conventional and non-conventional breeding techniques. Future crop yield growth will come from a combination of incremental increases in yield potential in rainfed and irrigated areas and from improved stress resistance in diverse environments, backed by policy reform and investment. Current investments come mainly from the private sector and are oriented towards agriculture in higher-income countries because of their purchasing power. However, these biotechnologies should reach developing countries where expansion of agricultural production is much needed for food and nutrition security as well as income enhancement. FAO (2000) suggests that biotechnology efforts should be made available to resource-poor farmers, while at the same time ensuring access to a diversity of sources of genetic materials in developing countries. This needs to be addressed through public funding and dialogue between the public and private sectors.

Climate

Though the potential effects of climate change are, as yet, not well understood, it is likely that developing countries will bear the brunt of the adverse consequences (IPCC 2001). Further, rural areas in developing countries will be the most affected, because agricultural production — which is especially vulnerable to climate change and variability — constitutes both their direct and indirect source of employment and income. Agriculture is the largest consumer of water resources, and variability in water supply is a major factor in the health and welfare of poor people in developing countries. If water scarcity increases as a consequence of climate change, for example, rural areas and the agriculture sector are likely to lose out to wealthier and more powerful industrial and domestic water users in the quest for limited supplies.

An integrated global analysis of the impacts of climate change and variability on the availability and use of water and the production and consumption of food shows that many developing regions will be harder hit than developed regions (Strzepek *et al.* 2004). In undertaking this analysis, IFPRI supports its IMPACT-WATER model with the use of WATBAL, a global hydrology model that uses data on climate, land cover, soil type, etc., and the Global Agro-Ecological Zones (GAEZ) model, which is used to determine crop yield potential (Fischer *et al.* 2003). Modeled climate scenarios apply climate shocks under various situations to a baseline scenario derived from historical data for 1961–1990. Irrigated and rainfed wheat production, for example, is significantly reduced in West Asia and North Africa under all climate change scenarios compared with the baseline, but effects in the European Union result in higher wheat production, largely because growing conditions improve with climate change.

Emerging evidence indicates that water resource variability may be a key determinant of economic growth and poverty alleviation in many African countries, including Ethiopia, Kenya and Mozambique (World Bank 2005). In Ethiopia, for example, a clear correlation exists between rainfall and economic growth. In these vulnerable countries, the primary water resource characteristic is extreme rainfall variability, the most obviously manifestation of which is endemic and devastating droughts and floods. Further research is necessary to clarify the scope and scale of the impacts of water variability on economic performance, natural resources and socioeconomic conditions, and the manner in which water shocks are transmitted through the economy.

Block *et al.* (2005) show that when climate variability is incorporated into food and water modeling for Ethiopia, the results change significantly for both agricultural and food security outcomes and policy conclusions. Poverty rates, for example, are significantly higher when climate variability is incorporated, and a wide range of possible poverty outcomes indicate potential catastrophic conditions during drought years (Block *et al.* 2005). Moreover, the impact of irrigation investment increases dramatically when climate change scenarios are taken into account because the buffering effect of higher irrigation investment on economic growth is captured. The impact of irrigation investment also increases significantly relative to investment in roads when climate factors are included.

Further research should examine what makes the economy vulnerable to water-related shocks, and how it can be made more resilient. In particular, research should assess how investment in irrigation and water resource storage and management — combined with policy reform — can mitigate the negative economic effects of water variability by identifying management interventions and decreasing vulnerability to shocks.

Climate change and variability in water supply, together with potential long-term changes in the cost of energy, could also dramatically change the cost–benefit ratio for water storage, irrigation and hydropower (i.e. large dams), making these investments more attractive despite the environmental and human relocation issues that dams raise. The appropriate level and location of future irrigation investments could also change dramatically. Policy analysis of mitigation and adaptation strategies for increased water and food security should be undertaken to prepare strategies and pathways for reaction to future impacts of climate change.

Policy Implications

Increasing water scarcity and declining water quality must be addressed through water management reform, along with economic incentives for water-use efficiency, increased water investments, and a focus on increasing crop productivity through agricultural research and technology.

Water management

One of the best ways to address many of the challenges facing the water sector is water management reform, including appropriate policies to improve water-use efficiency and support infrastructure investments. Rosegrant *et al.* (2002) describe several ways to improve water-use efficiency at the basin level, including phasing out groundwater overdraft in basins where this occurs, increasing committed environmental flows, increasing agricultural water prices, and reducing irrigated area development. Research in specific basins is needed to determine the potential for basin efficiency improvement. Efficiency improvements across all water-using sectors would have a major impact on overall water-use efficiency.

Various methods of improving water-management practices exist across sectors. In the industrial sector, for example, recycling can improve efficiency and lead to substantial water savings. Water-saving technologies have yet to be adopted in many industries, particularly in many developing countries. Beekman (1998) suggests that, in many industries, such technologies could reduce water use by around 50%. Cooling water, which constitutes about half of current industrial water use, is an area that could contribute major potential savings; it is also one in which some developing countries have already begun to make headway. Nickum (1994), for example, notes that industrial water-recycling rates in Beijing increased from 61% in 1980 to 72% in 1985, and total industrial water use declined steadily between 1977 and 1991, while output increased.

Substantial water-efficiency improvements are possible in the domestic sector as well. Leak detection has promise in many developing countries, where unaccounted-for water can often substantially reduce water-use efficiency. Various improved technologies, such as low-flow showerheads and low-water or waterless toilets can also help. Although some argue that savings will be small — because relatively little domestic water withdrawn is actually consumed, and much of it returns to rivers or the environment as return flows that can be reused elsewhere — domestic savings can make a big difference in densely populated coastal areas, where much of the water withdrawn is lost to the ocean. Lower domestic water withdrawals also generate economic benefits because water treatment and recycling costs are lower (Rosegrant 1997; Gleick *et al.* 2002). Other important domestic water savings derive from wastewater reuse. Domestic wastewater can be reused for many purposes, such as toilet flushing and irrigation of gardens, lawns and golf courses. Wastewater reuse for irrigation not only reduces water withdrawals, but also provides a source of nutrients, thus reducing the amount of chemical fertiliser needed. This has the further potential of providing economic benefits by reducing the need for both water and fertiliser Shuval (1990).

Despite the promising nature of these techniques for wastewater reuse, they should be used with caution. Negative health effects can result from wastewater reuse, particularly if it is used on vegetable crops that are eaten raw (especially those that grow low to the ground). Use of wastewater for the irrigation of fruit and other trees is quite promising, however, because the irrigation water does not reach the fruit.

Scope for improvement in the irrigation sector is significant at the technical, institutional and managerial levels. Technical methods include drip irrigation, sprinklers and the conjunctive use of surface and groundwater, as well as other technologies like computer monitoring of crop water demand; institutional approaches include establishing effective water-rights and water-user associations, and introducing water pricing mechanisms; and management practices include demand-based irrigation scheduling and improved maintenance of irrigation infrastructure.

Economic incentives for efficient water use

Setting appropriate incentive prices for water use is another key factor in promoting water-use efficiency across domestic, industrial and irrigation uses. Though the implementation of such policies is often politically unpopular and — if not designed and implemented properly — can negatively affect poor consumers and farmers, equitable water pricing would promote efficiency in the domestic and industrial sectors, provide incentives for conservation, cover delivery costs, and generate adequate revenues to finance water supply growth and expanded coverage of clean piped water. Industries in developing countries are likely to respond to such incentives, because they have not implemented many water saving technologies. In the domestic sector, equity for low-income users can be achieved through targeted rather than generalised subsidies and measures like increased block tariffs[2].

Imposing water pricing for agriculture is more difficult. It is a politically charged issue because pricing can reduce farm incomes and decrease the stability of water rights. In addition, irrigation water pricing can be difficult and costly to administer in developing countries, where farmers are often connected to one large irrigation system. It is, nevertheless, possible to design water-pricing systems that create incentives for efficient water use, recover some costs and protect farm incomes. Pezzey (1992), for example, describes a system in which a base water right would be established at major turnouts to water user groups or privately run irrigation sub-units, and the user group would then be responsible for internal water allocation. The base water right would reflect historical allocation, but in water-scarce basins would likely be somewhat lower; a fixed base charge would be applied to cover operations, management and depreciation costs. Above the base water right, users would be charged an efficiency price equal to the value of water in alternative uses; for demand below the base right, the same price would be paid to the water user. Strong water rights and the integration of water user associations help to preserve the farmer rights and make pricing schemes more politically feasible.

Water investment

Even with the significant financial, environmental and social costs of developing new water supplies, some expansion is appropriate to reduce supply variability in some developing countries, including Sub-Saharan Africa, some countries in South and South-East Asia and some parts of Latin America. Decisions regarding such investments are politically sensitive, however, and the full costs and potential benefits — including those not only for irrigation, but also for health, household water use and catchment improvement — must be considered.

Groundwater over-use is a major problem in many areas, so sustainable development of groundwater resources can also offer opportunities in many countries and regions. Conjunctive use of surface

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[2] This type of tariff structure has a very low per unit price for water up to a specified volume, after which users pay a higher price for volumetric blocks up to the highest level of consumption. In this way, high-income households that use more water cross subsidize low-income users.

and groundwater could be significantly expanded by:

(a) using wells for supplemental irrigation when canal water is inadequate or unreliable
(b) pumping groundwater into canals to augment canal stocks, lower the water table, and reduce salinity
(c) viewing a canal command and its imbedded tube wells as an integrated system, thereby optimising joint use of canal and groundwater resources (Frederiksen *et al.* 1993; Oweis and Hachum 2001).

It is crucial, however, that groundwater expansion is not undertaken without sufficient knowledge of associated aquifer properties.

Agricultural research and technology

Agricultural research and technology will continue to be of major importance in addressing future challenges facing the sector. Increasing crop productivity is a primary focus, requiring rural investment, water management and agricultural research. Investment in crop breeding targeted to rainfed environments is crucial to future crop yield growth, and must be continued. Research for irrigated areas should also be undertaken, with a specific focus on crop breeding for stress tolerance. Cereal yield growth could be improved by extending research downstream to farmers and upstream to using biotechnologies to assist conventional breeding, and, if concerns over risks can be solved, using transgenic breeding.

Investments in rural infrastructure are also important. Rainfed areas should receive priority in access to agricultural extension services, markets, credit and input supplies because of their more difficult and variable agro-climatic environments (and their comparative lack of infrastructure compared with high-potential irrigated areas). Progress may also be slower than in the early Green Revolution because new approaches for specific environments need to be developed and tested prior to broad dissemination. Investment in rainfed areas, policy reform and technology transfer will therefore require stronger partnerships between agricultural researchers and other agents of change, including local organisations, farmers, community leaders, non-governmental organisations, national policymakers and donors.

In terms of biotechnology, policy can support the safe development and application of available technologies, create incentives for technology innovation, create awareness of the need for and value of clean water and efficient water use, create disincentives to polluters (e.g. through fines) and incentives for effective water use (e.g. through effective water pricing), foster public–private cooperation and create private sector incentives for technology development.

Conclusion

Three emerging issues will have a fundamental impact on the future of water and food security through their effects on water management and agricultural productivity: aquaculture, biotechnology and climate.

The predicted rapid expansion in aquaculture, which offers much-needed (direct and indirect) economic, food security and nutrition benefits in developing countries, also has the potential to irrevocably damage the water resource base, along with related ecosystem health and biodiversity, if appropriate strategic planning and management action is not taken.

On the other hand, biotechnology — such as genetically engineered crop breeding to improve yields and nutrition and respond to stresses, like drought, salinity, and soil fertility — has high potential to improve the availability and accessibility of food, even under adverse environmental conditions. Biotechnology can also contribute to water management quality and by facilitating wastewater reuse through bio-remediation. Nevertheless, progress in resolving safety issues related to human, animal and ecosystem health, and other environmental and ethical concerns must be made quickly if these benefits are to be realised within the necessary timeframe.

Finally, the impact of climate change and increasing climate variability will have profound effects on water and food security, particularly in developing countries. The realities of such change must be incorporated into current planning and policy if farmers, and the agricultural sector more broadly, are to have any hope of successfully understanding, adapting to and managing the prospective risks. Simply recognising the significance of water quality and quantity in developing-country agriculture isn't enough: governments, policymakers and other sectors with water resource interests must address the complex challenge of setting policy and reforming water management to create the necessary incentives for efficient water use, increased investments in the water sector and support for agricultural research and technology that addresses water issues. These efforts are essential, and urgent, if the already overwhelming challenge of meeting future food and water needs is to be met, while at the same time preserving the natural resource base on which water and food security depend.

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