The Blue Revolution

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Water scarcity is going to be one of the critical limitations on agricultural production and our ability to feed the growing world population. However, the overall productivity of water use can be increased to help cope with increasing food demand.

For the majority of people growing up in developed countries, the issue of food security never arises. Australia, for example, has a relatively small population and in spite of droughts is an exporter of food.

However, elsewhere in developing countries, more than one billion people live in poverty (incomes less than about US$1.25 per day) and are often malnourished. Although this figure is unacceptable, it is arguable that one billion people might have died of starvation were it not for the Green Revolution of the 1960–70s.

The challenge is to double water productivity in many developing countries and regions. This will require a Blue Revolution in the way we deal with water.

The Green Revolution, led by Dr Norman Borlaug (who died on 12 September 2009), pioneered new, better-yielding and disease-resistant varieties of cereals (in particular wheat and rice), and with the help of fertilisers spread rapidly across smallholder agriculture in Asia and Latin America. This revolution enabled the world to keep up food production in the face of rapidly growing population pressure – until recently.

In 2007–2008, the world saw the emergence of a new food crisis. This crisis arose not because there was an absolute shortage of food, but because demand was increasing greater than supply, and as a consequence prices rose and the poorest members of society suffered most. At the same time some governments made irrational decisions that prevented trade of food from those countries with it to those without, further exacerbating the crisis.

To what extent are similar crises likely to happen in the future?

Drivers of Water Scarcity and Food Insecurity

To answer this question, we have to look at some of the fundamentals of agriculture in the world today. First, in spite of Dr Borlaug's concerns, we have done little to slow the rate of population growth. The global population is forecast to grow from about 6.7 billion to 9.0 billion in the next four decades. Some countries such as Pakistan are forecast to climb from 181 million to 335 million (an 85% increase), and this in a region already dealing with food security and environmental stress. Similarly, Africa is predicted to see population growth from 1.010 billion to 1.998 billion, a 95% increase.

Second, as people become more prosperous their dietary habits change. In much of Asia and Africa this means a move from diets based on cereals, fruits and vegetables to diets with a greater proportion of animal protein products. In China this has already occurred, with an increase in meat consumption whereas in India, a predominantly vegetarian nation, the amount of dairy products consumed has increased rapidly.

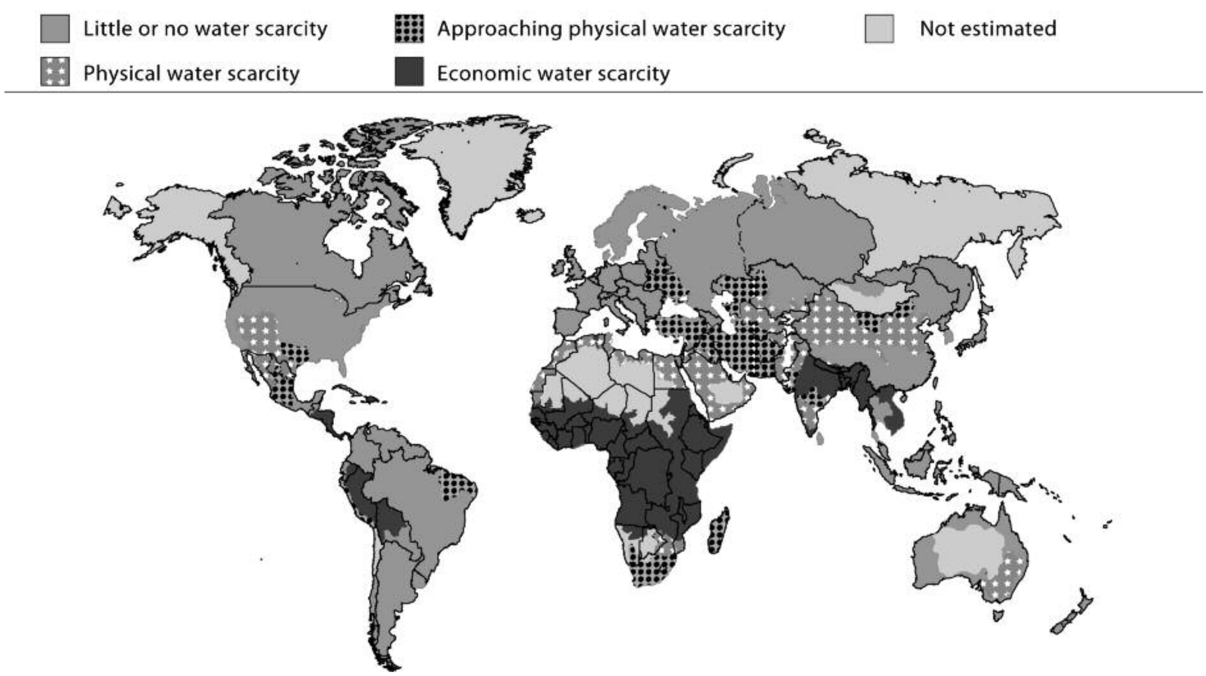

Figure 1. Water scarcity in 2000 (after Comprehensive Assessment of Water Management in Agriculture, 2007).
Definitions:

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

Dealing with both the increasing numbers of people and the change in dietary habits will require approximately twice as much food as is produced today. Agricultural production, of course, depends on inputs such as solar energy, fertilisers, land and water. Doubling the amount of food means doubling the amount of water use, and there are serious doubts about its availability, at least in the right places.

One litre of water is required to produce one calorie of food. Consequently, feeding 2.5 billion more mouths 2500 calories per day and taking into account dietary changes, crop/water productivity gains, post-production losses and food wastage will require 2500–6000 km^3 of additional water to be evapotranspirated (consumed and not returned to the hydrological cycle) each year.

Recent investigations by a team of more than 700 international scientists as part of the Comprehensive Assessment of Water Management in Agriculture (2007; http://www.iwmi.cgiar.org/Assessment) have demonstrated that if we continue with the currently low levels of water productivity, delivering the upper water requirement figure of 6000 km^3/year may be an unachievable goal. Countries like India are looking at a future demand for water that may be 30–50% greater than present supplies.

Furthermore, in countries where water is physically scarce, the majority of utilisable water resources have already been developed. A further downside of using all available water resources is that the environment always suffers, as has been demonstrated with the loss of floodplain habitats and the salinisation of the Coorong Lake System in Australia's Murray-Darling Basin.

With respect to land resources, a recent

International Water Management Institute/Food and Agricultural Organization of the United Nations study by Aditi Mukherji and others, published in 2009, has demonstrated that little suitable land is left available for agriculture in Asia and that intensification of production using irrigation has to be a likely solution. However, the situation in Africa is different, and water scarcity for much of the continent is due to a lack of investment in the necessary infrastructure to develop the available water resources (Fig. 1).

Food production competes for available water resources with fibre production and the production of biofuels from beans, maize and sugar cane. Many governments have policies that aim to substitute up to 15% of fossil hydrocarbon use with biofuels, but many of them have not factored in the impact this may have on water use and thus food production.

Additionally, a moderately rapid shift in population from rural to urban environments across the world is also impacting water resources. Larger towns and cities have larger water "footprints" and also compete for water with agriculture. A recent proposal to move water from the Murray-Darling Basin to Melbourne caused considerable uproar among the irrigation community. Reusing urban wastewater and run-off is, however, an opportunity to become more efficient.

Finally, many countries and regions, including southern Australia, are faced with the impacts of climate change. Similar impacts of higher temperatures, higher evaporation and more variable rainfall are also already being observed around the Mediterranean and in south-western USA, while glacier melting and retreat appears to be accelerating in mountain ranges in equatorial and the mid-latitudes.

So, although we need to collect more information and monitor more precisely the potential impacts of climate change, in many parts of the world the impacts are likely to exacerbate water scarcity. Ironically, the regions that may benefit most from climate change in terms of food production are those higher latitude countries such as Canada and Russia, while many poorer developing countries may see things get worse.

Until the world can effectively deal with out-of-control population growth, the outlook for

A Doubly Green Revolution

The Green Revolution in the 20th century enabled global food crop production to keep pace with rapid population growth. In developing countries, the area of cultivated land expanded but, most significantly, yields of rice, wheat and maize in irrigated and other high potential areas increased dramatically due to the widespread adoption of modern varieties and improved crop management practices, including fertilisers and other agrochemicals.

Attention subsequently turned to assessing the ecological costs associated with the Green Revolution and, additionally, the need to increase the productivity of marginal lands, which are particularly susceptible to degradation and had been relatively bypassed by agricultural researchers. These two research thrusts emphasise conservation as well as productivity, and have been labelled as a doubly Green Revolution.

Doubling global food production in the 20th century required a 6.9-fold increase in nitrogen fertiliser use and a 3.5-fold increase in phosphorus fertilisation. These nutrients were largely applied to rice, wheat and maize grown in high potential areas. Resulting accumulations of nutrients on-site and in surface- and groundwaters have created serious environmental problems.

With increased urbanisation these pollution problems are aggravated in densely populated areas and in intensive animal production systems, where nutrients build up due to imports of foods and feeds. Research shows considerable benefits can be gained by recycling nutrients in wastewater and solid wastes in peri-urban agriculture, but actions are needed that address associated health issues.

In the productive cereal-growing areas, soil fertility can be improved through the adoption of minimum tillage systems that conserve crop residues. In the developing countries, farmers in the wheat-growing areas in West , South and East Asia, and in the cropping systems of Brazil, have widely adopted conservation tillage. The area under conservation tillage globally has been estimated at more than 60 million hectares, although much of this is in developed countries in North America and Australia.

The win–win nature of conservation tillage is shown by an estimated increase in crop yields by 20–40 kg/ha for wheat and 10–20 kg/ha for maize for each one tonne increase in the organic carbon pool of degraded cropland soils. The reduced emissions of carbon dioxide are also important, although nitrous oxide emitted from nitrogen fertilisers continues to be a both the provision of plentiful fresh water supplies and adequate food has to be one of major concern. However, that is not to say that we can't deal with many of the water and food problems. The Green Revolution of the last century proved Malthus (1766–1834), a British philosopher who argued that population growth would be checked by famine or disease, wrong.

This time around I believe that the solution to prove Malthus wrong has to be a Blue Revolution that puts provision and access to fresh water and improvement in water productivity and reuse at the top of the political agenda. Plant scientists argue that they can breed new "super" crops that are heat-, salt- and drought-resistant. This will probably happen and will be a valuable weapon in the arsenal brought to bear on climate change.

However, to double food production needs up to twice the present water usage, and it is unlikely that crop breeding alone will allow doubling of yields in the next 40 years if we can't meet the basic water requirements of plants, particularly if climate change impacts affect these detrimentally. Furthermore, given the impact of the previously described factors that impinge on water, it is highly likely that the share of water resources going to agriculture may diminish over the forthcoming decades, making this task even harder.

Physical Solutions to Water Scarcity and Food Security

To ensure food security over the next decades, a number of actions are necessary. Many of these are related to physical measures that happen in the water supply networks and in farmers' fields.

An equal number of actions are those related to changing the way we think about, govern and manage water. These are often harder to take than simple engineering and agricultural measures.

Fundamental to the physical challenge is that of making water use more productive. This means increasing the yield of crops per volume of water used.

Even better would be looking at water productivity in terms of yield per unit of evapotranspiration. Whilst efficient farmers in

problematic greenhouse gas.

Research to develop knowledge-based nutrient management for rice and other cereals promises to improve input efficiency, thus reducing greenhouse emissions and pollution. Urea use is a particular problem with rice due to ammonia losses from fertiliser broadcast into the paddy water. In this regard, progress is being made in low-cost labour areas of Asia with village-level briquetting systems for deep placement of the urea – a significantly more efficient technology. Other strategies showing progress include the breeding of nutrient-efficient crop varieties, such as maize, that produce higher yields based on more effective patterns of uptake and growth.

At the other end of the spectrum, nutrient depletion due to inadequate input use in marginal lands looms as a major economic problem in many African countries and in the rain-fed areas of Asia and Latin America, where land is classified as marginal because of low and erratic rainfall and/or steep slopes. For African countries the average replacement costs for nutrients removed annually in harvested products and by soil erosion is 7% of agricultural domestic product.

While farmers need to use whatever organic residues are available, intensification of cropping with continuing harvests requires external inputs to maintain soil fertility. Addressing this problem requires policy interventions to assure markets for produce as well as for inputs; in the latter case the issue of vouchers for fertilisers to smallholders is a promising approach. Research shows that the adoption of agroforestry systems based on legume shrubs that fix nitrogen can significantly enhance soil productivity, and at low cost.

The steep lands of the humid tropics, which are commonly farmed by shifting cultivators, present special problems because poor land management has negative off-site impacts on water flows and sediment loads. When shifting cultivation intensifies to the point that this marginal land is cropped annually, the soil is subjected to erosion and soil organic matter levels decline.

Research shows that reducing land and water degradation, alleviating poverty, and curbing migration to the cities require a shift from subsistence cropping to some form of mixed cash cropping utilising contour planting of shrub legumes to stabilise the hillsides. In some of these areas, the Landcare model of community-based natural resource management has been very successful.

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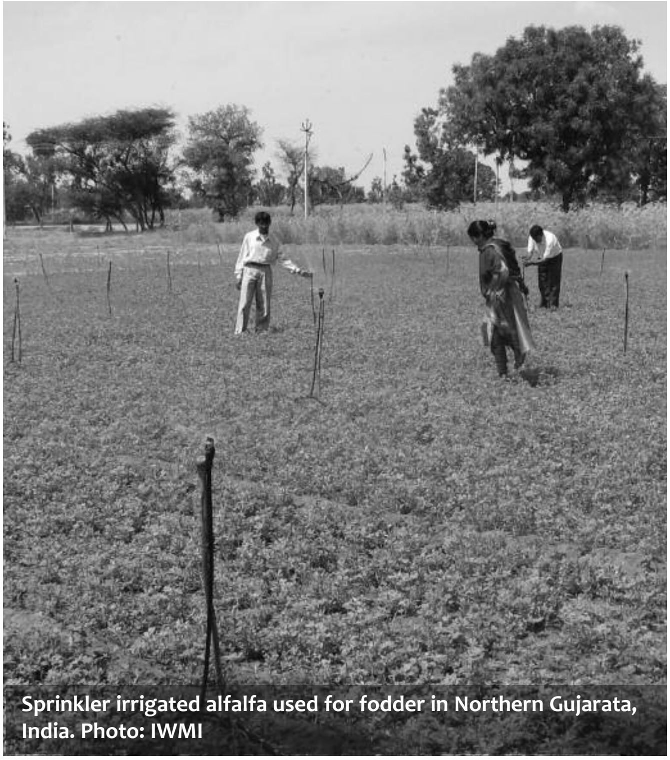

Sprinkler irrigated alfalfa used for fodder in Northern Gujarata, India. Photo: IWMI

both irrigated areas and rain-fed farming systems can produce high yields and can also be very water productive, this is not the case everywhere, and a target of doubling water productivity in many countries is achievable. To do so, however, would require significant investment in water-loss reduction from water storages and canal distribution systems and similarly require significant on-farm investment in better water management technologies as well as access to fertilisers, disease-resistant seeds and the application of good weed control.

In areas currently without irrigation there needs to be a consideration of groundwater or rainwater harvesting techniques as a means of insuring small farmers against wet season failure. All sorts of water storages, from large dams to artificially recharging groundwater, need to be considered, particularly in areas likely to be hit by increasing climate variability and those regions such as much of Sub-Saharan Africa that lack storage infrastructure.

Recent International Water Management Institute work has demonstrated that access to shallow groundwater across much of the northern part of Ghana and southern Burkina Faso in West Africa provides valuable income as well as greater food security to poor farmers yet has no appreciable long-term impact on the groundwater resources.

Finally, much greater attention needs to be paid to the safe recycling of wastewater for all uses including agriculture, environmental flows, industrial water and even drinking water.

Social and Governance Solutions

Technological and engineering solutions to double food and feed production are potentially achievable if we can get the social, economic and environmental settings right. However, overcoming the social, economic and sometimes environmental impediments and obtaining the needed financial investment is the hard part.

Institutional and governance arrangements for water often were designed in the middle of the past century based on now-inappropriate colonial models where water was viewed as an infinite resource. Governments lack incentives to implement the reforms necessary to ensure more productive and equitable use of water. Fear of potential political repercussions for those who push reform permeate every level of the water and agricultural sectors.

Furthermore, many individuals and non-governmental organisations consider access to water as a basic human right. However, this human right accounts for a very modest amount of total water use. The rest, over 90%, goes to beneficial uses and the environment. The biggest beneficial user is clearly agriculture. Subsequently, we need to seriously consider water pricing schemes for larger water users that force them to become more efficient.

Measures that governments can take to drive up agricultural water productivity are non-existent in many countries. Clearly, the first measure has to be the development of effective water allocation policies that can be used to reduce allocation as the total pool shrinks or when demands for water resources from other sectors increase. However, allocation policies depend on good water availability measurements, historical data and models, and defined water rights.

Reduced allocations must be accompanied by support mechanisms for farmers that can improve on-farm efficiency. Currently, if a farmer invests in improving productivity, he or she can keep the water saved and use it to increase the area irrigated. While this may increase food production, it does not solve the problem of reallocation of water to other economic sectors, or to the environment. A real challenge here is to try to develop incentives that link broader society to farmers and lead to the payment by broader society of farmers for the improved environmental services and other benefits that result from improved on-farm water savings.

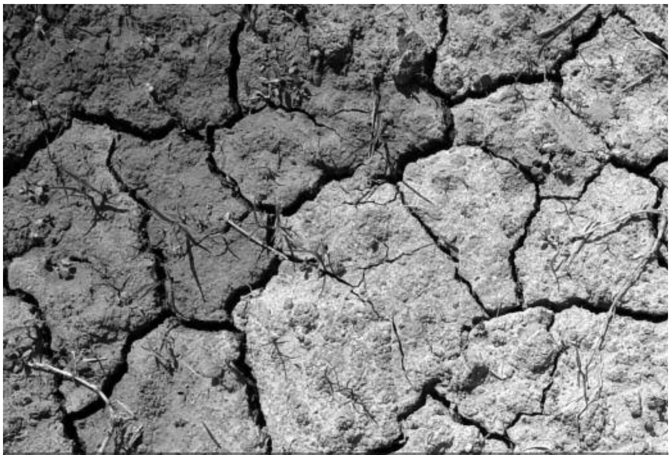
A good example of governance systems not keeping pace with on-ground reality comes from India. Here, the shift from planned and regulated (albeit inadequately) surface irrigation systems to anarchic pump-based irrigation systems based predominantly on groundwater, as described by Tushaar Shah (*Taming the Anarchy: Groundwater Governance in South Asia*, 2009), has been of major significance.

However, the inability of state governments to regulate water use in such systems can create scenarios of groundwater overdraft and exhaustion. These can then lead to regional food crises and social disruption. What is needed is a complete rethink of the old surface water supply system – how it can have dual functionality by providing surface water to those still using it as well as recharging the groundwater.

At the international level, we need governments in water-scarce countries to realise that growing bulk foodstuffs with precious water is economic and environmental nonsense. Trade regimes need to be opened up to maximise the export of water (virtual water) from water-rich to water-poor countries in the form of bulk agricultural products. The concept of national food security is not a sensible one in really water-scarce countries, but is often still followed because of overall security fears.

Can Australia Provide Leadership in Water Reform?

In the search for improved governance, we must examine the potential solutions that have been and are currently being developed. In parts of Australia and several other countries, a series of mechanisms are used to regulate water use and allocation that depend on seasonal available supply. In the Murray–Darling Basin, a new system of separation of water and land rights, water trading and water pricing based on supply and demand has evolved through a combination of market and political forces. The result: water is traded from low- to high-value uses, which can potentially allow for a market mechanism to trade out of agriculture and into urban areas. It is a model worth exploring elsewhere. So long as individual water rights and allocations can be defined, farmers have opportunities and incentives to sell temporarily or permanently. Governments also have opportunities to buy out system tail-end users, improve overall system efficiency and to buy water for environmental flow purposes.


Cracked soil due to drought in Central Asia. Photo: IWMI

Conclusions

Water availability and scarcity are inextricably linked to the issue of food security for many nations. Although the likely demand on water and food over the next few decades will be high, there are a number of opportunities in which scientifically and socially based solutions can be applied to increase food production so that all can be fed and adequately nourished.

However, to achieve this end result we all have to change the way we perceive water and food issues and learn to do business much better at the political, governance, engineering and agricultural parts of what is a very complex system.

The challenge is to double water productivity in many developing countries and regions. This will require a Blue Revolution in the way we deal with water.