Land Use and Water Resources Research

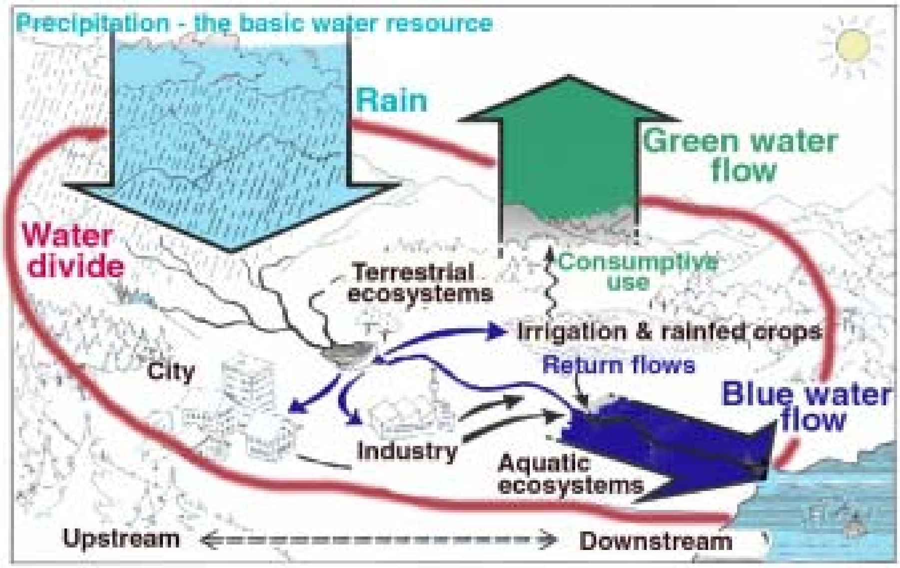
Water cycle and people: water for feeding humanity*

Malin Falkenmark

Stockholm International Water Institute

Abstract

The distinction of 'blue' (liquid) and 'green' (vapour) water flow is introduced to make possible an assessment of water flows to be appropriated for future food production. The author offers a 'backcasting approach' in assessing the consumptive water requirements for feeding humanity by 2050 and from where the needed water may be provided (irrigation, crop-per-drop improvements and horizontal expansion into grasslands and forests). She concludes that food security will demand a major shift in thinking.



Introduction

Many future-oriented studies on global food supply tend to take an engineering and mercantile approach: what is probable in terms of increased food production and market responses? In other words, taking a *forecasting* approach. The shortfall in uncovered food needs — mainly in S. Asia

*A longer version of this paper is published under the title Falkenmark, M. & Rockström, J. "Neither water nor food security without a major shift in thinking. A water scarcity close up". In: *Perspectives in World Food and Agriculture 2003*, J.Miranowski & C. Scanes (Eds), Iowa State University Press and Subsaharan Africa — are left as a 'hidden food gap', estimated to be twice as large by 2020 as total developing country imports at that time at 360 and 190 M ton yr^{-1} respectively (Conway, 1997). This study takes the opposite approach. If we want the entire world population to be nutritionally well fed by, say, 2025 what would that imply in terms of additional consumptive water use, i.e. taking a *backcasting* approach?

The conventional approach to crop production distinguishes between irrigated and rainfed agriculture. It pays most attention to the former in view of the evident competition with other water uses and users. Most of the global food production, however, originates from rainfed agriculture. Rainwater represents the ultimate water resource, part of which vaporises during plant production (the so-called green water flow), while the rest forms runoff (so-called blue water flow). Irrigated agriculture represents some 70% of the overall blue water use of 3900 km^3 yr^{-1}. Agriculture consumes twice as much, however. Huge amounts of rainwater — in fact two-thirds of all continental precipitation — are consumed in plant production in natural and anthropogenic ecosystems (forests, grasslands, croplands). Moreover, altered plant mass production tends to be reflected in altered runoff production: a land use decision is thus also a water decision.

There is, however, a broad grey area between the two modes of agricultural water use. From the perspective of the crops, the key is the amount of water available within the root zone, not how the water got there, whether as infiltrated rainwater or applied as irrigation water. The Green Revolution had its focus on irrigated agriculture. But by dryspell mitigation efforts, rainfed agriculture can be upgraded in the tropical regions, doubling or even three-folding the yields, for example by small scale, short-term protective irrigation based on rainwater harvesting (Rockström and Falkenmark, 2000).

Water requirements

Let us first look at how much water that will literally be consumed — vaporised — in food production at an acceptable nutritional level for each individual. Based on crop water requirements to produce different food stuffs, the composition of different diets, and the food needs for a nutritionally acceptable diet, Rockström (2002) arrived at a *per-capita* water requirement of 1300 m^3 p yr^{-1} in consumptive water use, irrespective of whether the roots get the water from infiltrated rainfall or from applied irrigation water. It should be noted that this corresponds to some 70 times the basic water need on a household level, as suggested by Gleick (1996) at 50 litres p d^{-1}.

In this backcasting approach, we are interested in the gross amount of water that will be consumed in producing enough food to feed tomorrow's population. We have therefore to assume 1300 m^3 p yr^{-1} for each additional world inhabitant, but we also have to include the additional food needed to raise the nutritional level of all the undernourished individuals in today's world. Rockström (ibid) arrived at the following global amounts of additional green water needs:

- by 2025 — + 3800 km^3 yr^{-1}
- by 2050 — + 5600 km^3 yr^{-1}

At the regional level he estimates the following increases between now and 2025:

- Subsaharan Africa (460 to 1450 km^3 yr^{-1}) — 3.1 times the present
- Asia (except Soviet) (2830 to 6210 km^3 yr^{-1}) — 2.2 times the present

Potential water sources

These results suggest that huge additional amounts of green water flow will have to be appropriated for feeding humanity on an acceptable nutritional level. The crucial question is from where will this water originate?

There are three basic sources:

- *irrigation*, i.e. redirecting even more blue water for meeting green water needs - an alternative that is opposed strongly by environmentalists however, who feel the need to conserve most of the remaining streamflow for the benefit of aquatic ecosystems (IUCN, 2000);
- *increased 'crop-per-drop' efficiency*, i.e. whereby losses in current agricultural water use (irrigated as well as rainfed) could be put to productive use, in other words transforming pure evaporation losses from wet surfaces into productive transpiration through the plant - a solution advocated strongly in the international water community debate;
- *horizontal expansion*, by which green water now used for plant production by natural ecosystems (forests, grasslands), would be used instead for production of crops.

Rockström (ibid) has analysed the potential contribution from the first source, resulting in the following possibilities to meet additional green water needs by 2050:

- irrigation: — maximum 800 km^3 yr^{-1}
- crop-per-drop improvements — maximum 1500 km^3 yr^{-1}
- horizontal expansion — minimum 3300 km^3 yr^{-1}

Difficult balancing between water for food and water for nature

As indicated above, there is strong opposition from ecological circles to both large-scale increase of irrigation (because of the negative effects on aquatic ecosystems) and also to horizontal expansion (because of the effects on terrestrial ecosystems). It is evident from the sheer scale of these assessments, however, that informed trade-offs will have to be made. What problems will have to be addressed? What sort of balancing between man and nature will be needed? And what would the criteria for setting priorities be? Let us look closer at the three alternatives.

- *Irrigation* involves redirecting blue water during the growing season, turning it into consumptive green water flow. During the wet season the effect will basically be reduced flood flow. During the dry season the resulting reduction in dry season flow may be more problematic. Current examples of river depletion are offered both by the Yellow river, which in 1997 went dry in the downstream stretch seven months a year, and by the Aral Sea region where the river inflow has decreased to 10% of the natural flow, causing lake evaporation to take over and the lake to shrink dramatically. Through water storages in reservoirs, wet season flow can be stored for use during the dry season.

- Improved water use efficiency (*crop-per-drop*) can be secured in different ways in both rainfed and irrigated agriculture. On the one hand, infiltration potential can be improved by soil conservation measures so that more rainwater can infiltrate. This will also reduce the destructive overland flows that tend to cause severe erosion damage in large parts of the tropics. On the other hand, evaporation losses between plants can be reduced by increased foliage, for instance by protecting the plants from dryspell damage to the roots (protective irrigation during dryspells with locally harvested overland flow). Depending on where the harvested blue water was heading — on its way to evaporate or on its way to a local stream — the downstream effect may or may not happen. In irrigation systems, losses may be reduced by covering the canal or by lining the canal. In the latter case, however, groundwater recharge is reduced, with possible downstream effects on groundwater-fed wetlands or on wells used for local water supply.

- *Horizontal expansion*, i.e. turning forested land or grasslands into croplands, may have effects on rainwater partitioning and therefore on local runoff generation. In cases where a year-round green water flow from a forest is replaced by a seasonal one from an annual crop, groundwater recharge and/or runoff production may increase. In Australia, where immigrants from Europe cleared the woodlands for croplands, the outcome was a disastrous, regional scale water logging and salinisation (so-called dryland salinisation). The hydrological consequences of the other main alternative, i.e. replacing grasslands for croplands, are more complex and difficult to generalise.

The balancing needed between water for existing ecosystems and water for feeding a growing human population will self-evidently be difficult. IWMI (International Water Management Institute) has brought together a large number of other international organisations, among them IUCN (International Union for Conservation of Nature), to initiate a broad dialogue on water, food and environment. The aim is to find the way out of this considerable dilemma, which will need large-scale international attention in the next few decades.

Considerable regional contrasts

The options open for increased food production are different between different world regions. The two regions where the dilemma is largest are the semi-arid regions in Subsaharan Africa and S. Asia that were left with large 'hidden food gaps' in conventional studies. These are the two regions with the largest under-nutrition and at the same time the most rapid population growth.

In S. Asia, horizontal expansion is highly limited: most land is in use already and there are no reserves of arable but still unused land. The options are therefore 'crop per drop' and irrigation. To the degree that this will not be enough to feed tomorrow's populations, food will have to be imported.

In Subsaharan Africa, however, plenty of unused land remains, mainly under forests. Since 95% of farms are rainfed and there is only limited irrigation, crop-per-drop in the sense of increased irrigation efficiency will contribute only to a limited degree. There are, however, considerable possibilities for upgrading rainfed agriculture, provided that dryspell mitigation can be developed on a regional scale and be made attractive among the Subsaharan farmers (Rockström and Falkenmark, 2000). During the transient process of social change and changing farmer attitudes to risk assessment, food imports will probably have to play a central role (largely through food aid).

A new research area appears in this connection: the water perspective of food trade and the future flows of so-called *virtual water*. This is the water involved in the production of food transferred from one region, better endowed in terms of water needed for food production, to a water-deficient region with large food needs. Japan has recently assessed its dependence on virtual water flow to be almost 20% more than all domestic withdrawals (104 km^3 yr^{-1} as compared to 89 km^3 yr^{-1}: Oki, 2002).

Conclusions

This backcasting study of the water needs for feeding humanity in the next half century has shown that major changes can be foreseen. The reported fiasco of discussions in Johannesburg on future food production should therefore cause serious concern. Already, the next generation will need an additional amount of green water that is equivalent in size to ALL blue water use by humanity today. In the second generation, another 60% will be needed. The study has also shown that past approaches, limited to irrigated agriculture and blue water needs only, will be totally insufficient, with only some 14% of the additional water requirements covered.

In other words, there will be no food security without a major shift in thinking. A new approach will have to be taken to crop water requirements and the possibilities available to meet those requirements. It is no longer merely irrigation needs that will remain in focus, but overall water requirements, whether met by infiltrated rainfall or supplied as irrigation water. Plant production will have to be addressed by referring to both green and blue water flows.

Crop water requirements represent green water flows. But when these flows change, runoff generation will be influenced and therefore also blue water flow. Conventionally, such relations were covered by the concept 'water balance changes' but did not attract much interest, probably because the evaporative demand in the temperate zone tends to be too low to generate distinguishable streamflow changes. Southern Africa, however, speaks of forest plantations as 'streamflow reducing activity' for which foresters will have to pay. In a way, therefore, water consequences of land cover change, as experienced in Australia and southern Africa, can be characterised as 'arid zone surprises'. Adequate attention has therefore to be paid also to the potential streamflow changes of closing the hidden food gap.

In the new approach, agricultural engineering will have to be complemented with agro-ecohydrology. There will have to be active bridge-building between ecology and hydrology so that the conceptual void between climate, plant production and streamflow can be filled. Finally, virtual water flows will have to be focused. Today's optimistic references to food import and virtual water when discussing food security in water-short regions, will have to be complemented with a more realistic analysis of the regional sources for that virtual water. From where will there be enough food to import? Will it be possible to close the global virtual water balance? Or is the world approaching the carrying capacity of the planet — a concept denied intensely in broad circles in the past?

References

Conway, G. 1997. *The doubly green revolution*. Cornell University Press, Ithaca, New York.

Gleick, P. 1996. Basic water requirement for human activities: meeting basic needs. *Water International* **21**:83–92.

IUCN 2000. *Vision for Water for Nature*. IUCN, Gland, Switzerland.

Oki, T. 2002. World water resources and global climate change. *Frontier Newsletter* No 19, July 2002. Institute of Industrial Science, Tokyo.

Rockström, J. 2002. Water for food and nature in savannahs: vapour shift and drought mitigation in rainfed agriculture. Manuscript.

Rockström, J. and Falkenmark, M. 2000. Semiarid crop production from a hydrological perspective: gap between potential and actual yields. *Critical Reviews in Plant Sciences*, **19**: 319–346.