Feeding Eight Billion People

Time to Get Out of Past Misconceptions

by Prof. Malin Falkenmark, Dr. Johan Rockström and Prof. Hubert H.G. Savenije

The water necessary to produce the food required for an expanding human population is usually discussed only as an issue of blue water (the water we use from rivers and aquifers). This discussion neglects all the food produced from rainfed farming, which is critical not least in hunger and poverty stricken areas with rapid population growth, areas that depend not on blue water but on green water (the soil moisture used by plants and returned as vapor flow). A shift in water thinking is essential in order to find realistic and sustainable options to feed the world of tomorrow.

Food security analysis requires a holistic understanding of water use

The key message from the first ten years of Stockholm Water Symposia was the need for a major shift in thinking in order to achieve water security. Because food production requires huge volumes of water, food security for rapidly growing populations can similarly not be achieved *without a major shift in thinking*.

One major misconception that is particularly common in the West is the dominant role of irrigation in today's water use. Agriculture is said to represent two thirds of all water withdrawals in the world, or twice as much as domestic and industrial needs: approximately 2600 Gm^3/yr of a total annual withdrawal of approximately 4000 Gm^3/yr (1). The problem is that these numbers represent a huge understatement and refer only to blue water flow (surface water and renewable groundwater), which is the water flow conventionally perceived as an economic resource. *What the statement neglects is the large amount of green water flow involved in current food production.*

Plants do not depend on blue water directly, in fact, but on the soil moisture taken up by the roots and released to the atmosphere. This green water flow involves huge volumes of moisture – in the dry climate regions some 1000 – 3000 m^3 per ton of grain produced.

Figure 1 clarifies from a global perspective the source of water to produce food in the world. Countries in green are mainly rainfed; countries in blue depend mainly on irrigation; and countries with diagonal lines have a blend of green and blue water withdrawals to produce food. *The map clearly indicates that world food production largely depends on direct use of green water in rainfed agriculture. In fact, some 70% of the analyzed countries depend at least 60% on green water for grain food supplies.*

Green water, blue water and associated policy ramifications

According to a recent estimate, the green water flow involved in rainfed agriculture (3) is some 5000 Gm^3/yr. This means that blue water-based irrigated agriculture accounts for 30% of annual withdrawals from the global cycle of altogether 9000 Gm^3/yr, and green water-based rainfed agriculture for 54%. In the big picture, agriculture therefore accounts for 84% of annual direct withdrawals from the water cycle, and rainfed agriculture is the dominant user.

Even more holistically, if we include the water to support the growth of grass on the world's permanent grazing land for meat production, then the role of grain agriculture shrinks rapidly. Permanent grazing accounts for approximately 75% of annual water cycle withdrawals, blue grains account for 8% and green grains for 14%.

Just these two simple examples lead to very different policy paths. In the conventional blue water assessments, the focus is strongly drawn to improving efficiencies in conventional irrigation systems, in fear of exhausting blue water resources. The 2nd assessment (where rainfed grain foods are included) leads to the realization that rainfed agriculture takes the largest bulk of the world's freshwater and is therefore in need of special attention. The 3rd assessment, where obviously meat production seems to be the dominant water withdrawer, may lead to a wider emphasis on range management (and e.g., studies on opportunity costs of permanent grazing lands).

Furthermore, green water is even more important as a basis for human well being since it sustains biomass growth in all biomes, which in turn delivers a number of crucial ecosystem services to society. The most obvious services are food, timber, fodder, renewable fuel and fibers, and the less obvious – but not less important – include biodiversity, micro-climatic conditions, carbon sequestration, etc. At present already some 63,000 Gm^3/yr of green water flow on average is estimated to be involved in sustaining the major biomes of the world, including forests, woodlands, cropland, wetlands, grasslands and grazing land (3). *This suggests a very high present dependency on green water flow,* which globally amounts to some 70,000 km^3/yr over land surfaces (Fig.2).

This green water dependency should be compared to the human dependency on blue water flow. Only an estimated 12,500 Gm^3/yr out of the overall blue water flow of around 40,000 Gm^3/yr is considered accessible for societal use. Evidently, the blue water withdrawals of 4000 Gm^3/yr represent a very small fraction of the overall water flow sustaining the human life support system.

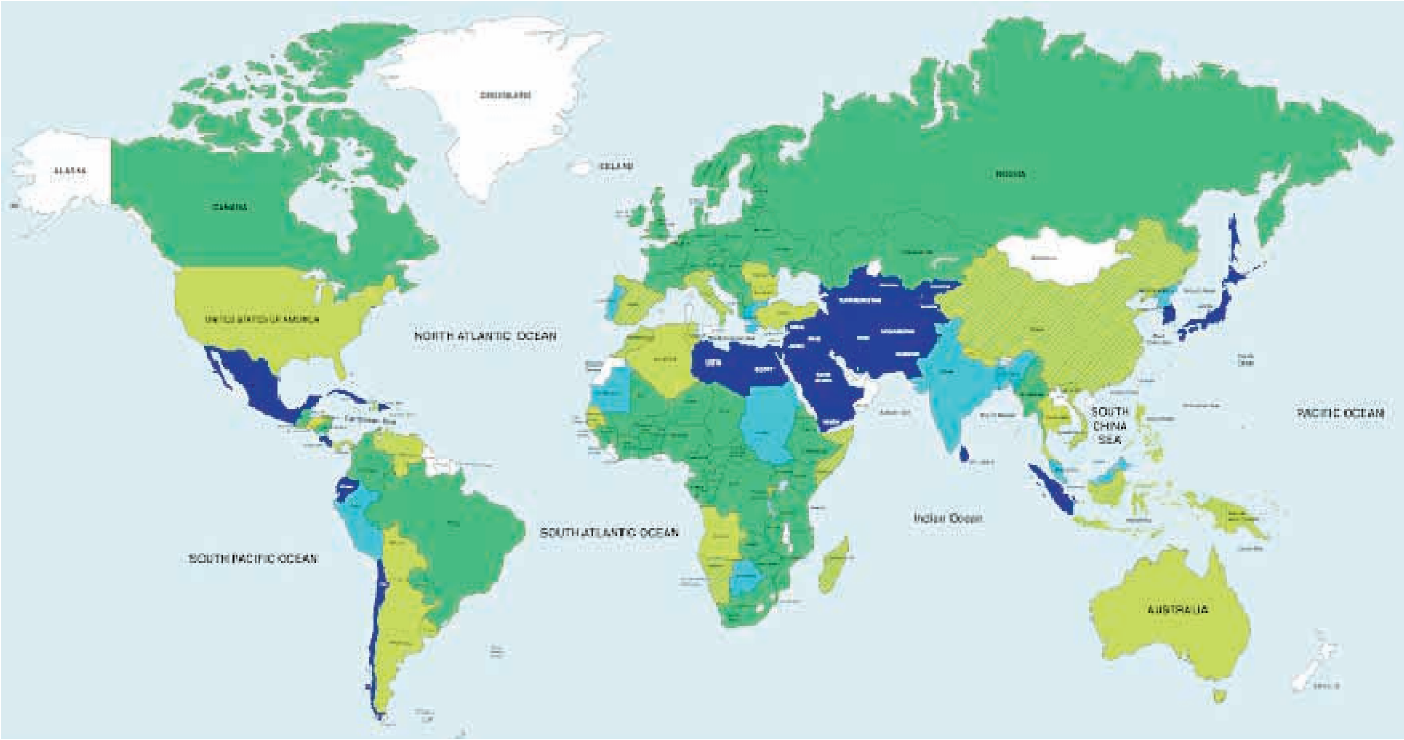
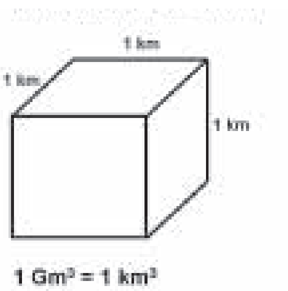


Figure 1. World map showing country dependence on green and blue water flows in the hydrological cycle. Dark green countries depend to more than 80% on direct return flow of green water in rainfed agriculture to sustain grain food production (i.e., the dependence on green water flow in rainfed agriculture to sustain national food production exceeds 80% of total annual water use in the food sector). Green countries have a green water dependence > 60%. Dark blue countries depend to > 80% on blue water use in conventional irrigation. Blue countries depend to > 60% on blue water use and countries with diagonal lines have a mixed blue/green dependence (Green dependence ranging from 40 – 60%). White countries lack data for estimation (2).

Food for eight billion people – from what water?

Assuming a per capita water need for food of approximately 1200 m³/p/yr, the overall water needed to feed a projected world population of 8 billion in 2025 would amount to some 9600 Gm³/yr. If all this were blue water, it would together with an increasing demand for domestic and industrial water use, would reach very close to the limit of accessible blue water in the world's rivers and aquifers. Fortunately the total amount of rainwater wetting the continents amounts to more than five times as much, i.e. some 110,000 km³/yr, an important aspect when considering food production increases.

Basically, crop yields are a function of the water in the root zone and how much of that water that the crops are able to take up and use for production of plant biomass. In drought-prone areas, plants are not very good at absorbing more than a fraction of that amount due, for example, to physiological damage during dryspells resulting in extremely poor yields (often less than 1 ton/ha). Improved crop production is basically an issue of both rootzone water security and root uptake ability. *Overcoming the damaging effects of dryspells, droughts and crusting soils is therefore a critical task.*



There are different ways to secure enough water in the root zone – irrigation being the one most widely discussed. In the tropical rainfed situation, the yields can be considerably improved if two barriers are addressed: *soil deficiency*, which hinders rainfall infiltration and can be addressed by conservation tilling, and *plant deficiency,* which is caused by dryspell damage hindering the roots' ability to take up more than a fraction of the rootzone water. This deficiency can be mitigated by small-scale protective irrigation during dryspells based on locally harvested rainwater or overland flow, collected in small farm tanks that can be easily managed by the farmer. Shallow groundwater is an alternative resource for dryspell protection and is, for example, still largely untapped in many parts of sub-Saharan Africa (but highly over-exploited elsewhere, as in many parts of India). The advantage with protective irrigation from groundwater is that there are no evaporation losses from open water storage.

In semi-arid areas irrigation from groundwater during the dry season is generally not possible. But supplementary irrigation during the wet season to bridge dry spells generally is. During the dry season the well can be used for domestic purposes, having a high social value (5).

Research on the farmer's field (2) suggests that minimizing these barriers by simple on-farm soil and water management may allow 5- to 10-fold increases in yields compared to current on-farm yields of 0.5-1 ton/ha, provided that nutrient deficiency is properly mitigated. Reduced risk of crop failure is a necessary step to encourage the farmer to invest in fertilizers, pest management and improved varieties.

Large untapped potential: tropical rainfed agriculture

A second major misconception – see for instance the February issue of *Scientific American* (4) – is that most of the additional food for a growing humanity will have to be produced on irrigated lands rather than rainfed lands. A regional analysis suggests that the situation is more complex. In countries experiencing the fastest population growth and the largest undernutrition levels, only some 5% of the cropland are irrigated. The vast majority of the farmers in sub-Saharan Africa depend on rainfed agriculture generally with holdings of less than 5 ha. Even India – one of the world's "big-four" irrigating countries (together with Pakistan, Egypt and the USA) – still depends for approximately 60% on rainfed agriculture.

In other words, *rainfed agriculture still plays a central role in sustaining livelihoods of rural communities even in countries with a long history of irrigation development.* The reason is simple. Large irrigation developments suffer from substantial energy requirements, and large losses are involved in moving water long distances – losses that in fact benefit downstream communities since water will move where gravity takes it. These costs can be a reason why irrigation development has stagnated over the past 20 years in many drought prone developing countries. Poor rural communities who are in most need of water are out of reach of irrigation development, because they live upstream of the storageable water, and moving water against gravity is very expensive.

Now, this is not to say that irrigation has a minor role to play in future food security. It covers 1/5 of the world's cropland, produces 30-40% of world cereals, and still presents untapped potentials that probably have to be developed if we are to stand a chance to avoid social food-driven disasters over the next 50 years. Furthermore, it should be noted that irrigation systems are seldom as inefficient (in terms of water use) as often is stated. Excessive water application in irrigation is often reused as groundwater elsewhere, and e.g., in Egypt where irrigation efficiency generally is quoted at 50% or less, the excess water applied is a necessary part of the system as it assists in flushing out salt accumulation in the soil.

The point is that there is a strong likelihood that developing rainfed agriculture may present an even larger untapped potential than irrigated agriculture in future food production improvements, since rainfed agriculture is often producing suboptimally and has a large capacity for improvements.

Irrigated or rainfed – fuzzy distinction

The increased attention now going to the potential to upgrade rainfed agriculture on the farmer's field by simple protective irrigation (2) highlights the increasingly fuzzy distinction between irrigated and rainfed agriculture. The key issue in undernourished, poverty-stricken regions, where most of the farmers depend on small-scale rainfed agriculture, is how to improve rootzone water security and root uptake capacity over time. In these regions – mainly in the arid to dry-sub-humid belt – rainfall is characterized by intensive storms but high erraticness over time. In other words, there is a high risk for dryspells despite reasonably good rainfall totals on a seasonal or annual basis. An opportunity to upgrade such farming systems is to blend different green and blue water management techniques in order to improve rainwater use efficiency: *more crop per drop of green water.*

Mitigating dryspells through protective irrigation has crucial implications on risk management. There is ample evidence showing that a reason for low investment in soil fertilization, improved crop varieties and pest management, is the high risk of losing the invested capital due to yield loss through unpredictable dryspells. Reducing this risk, by giving the farmer a management tool to handle the erraticness factor of tropical rainfall, can be an entry point for improvement in farming systems. The potential should not be underestimated.

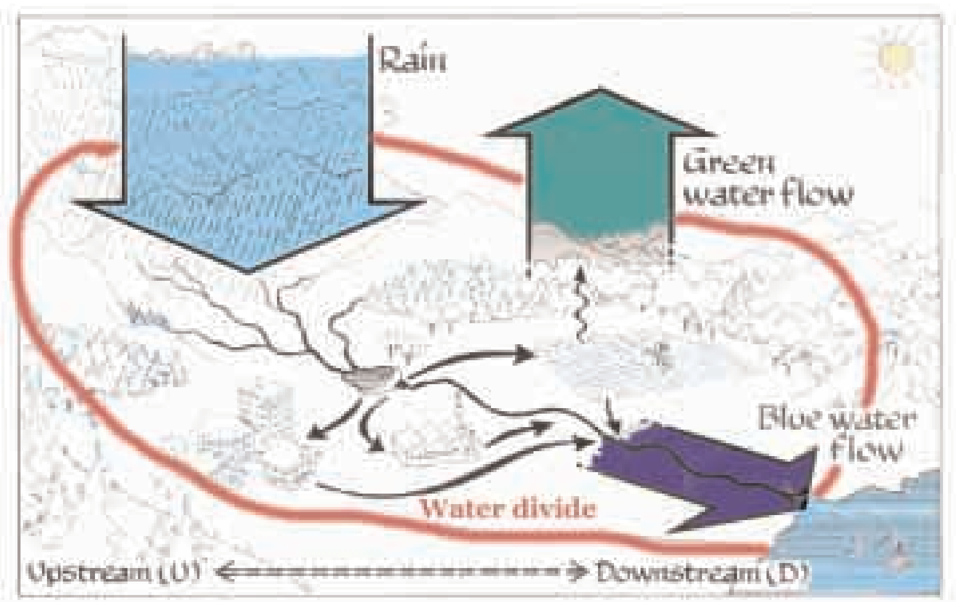


Figure 2. Green/blue water flow in a river basin, where rainwater divides into a green part returning to the atmosphere as evapotranspiration, and a blue part forming the surface runoff.

Producing more crop per drop of what?

A crucial issue for future water resources management is whether or not it is possible to produce more food per drop of water – but of what water? Water use efficiency can be measured between both different food outputs (e.g., grain or total biomass) and different water flows (e.g., per unit rainfall, transpiration flow/productive green water or total green water, including non-productive evaporation losses). *For management potential, attention must be paid to downstream consequences.*

It may be relatively easy to improve the amount of crop produced *per drop of rain,* but that "improvement" may impact water availability for environmental functions and human activities downstream (if, e.g., runoff is reduced through soil and water conservation, improving soil infiltration and enabling more soil moisture uptake by the crop).

Producing more crop *per drop transpired* is difficult, although bridging dryspells can result in very significant leaps. For example, a crop that transpires at its full capacity during germination and vegetative growth suddenly suffers a serious dryspell during flowering, following again by full transpiration until harvest. The result is relatively high cumulative transpiration but very limited – perhaps even zero – grain yield. Water use efficiency for grain can be boosted through small additional volumes of water during dryspells. But since this normally entails the use of some blue water, it may impact on downstream water uses.

The most commonly used water use efficiency indices (in scientific literature) is grain crop *per drop of total green water flow* (including evaporation losses). An interesting option, often debated, is to what extent the non-productive evaporation losses can be converted to productive green water flow (as transpiration). *This internal vapor shift is a win-win option: more food can be produced per unit vapor without impacting either the atmosphere (which does not care from what vapor path its thirst is satisfied), nor the downstream water users.*

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As non-productive evaporation has shown to account for up to 50% of rainfall in semi-arid tropical cropland, there seems to be a large potential source to scoop from. It is possible to improve this ratio, through various land management techniques, involving mulching, intercropping, dry planting and improved soil fertility management. All these practices have the common goal of maximizing a living canopy or mulch cover that shades the soil surface in order to minimize evaporation losses.

From the semi-arid farmer's perspective, *rainfall use efficiency* is the most relevant indicator of system performance, as it incorporates all water flows that can be influenced through soil and water management. However, it is important to note that water use efficiency is generally not a high priority among farmers even in drought prone tropical environments, but rather a stable supply of water over time is what the farmer wants to *minimize risks of crop yield reductions.*

Observed water use efficiencies in the semiarid tropics with the earlier indicated very low yields are extremely low, often 6000 m^3/ton grain or even more. The explanation is that a large part of the green water flow is non-productive and goes back to the atmosphere as evaporation from wet soil between the plants, and the productive part passing through the plants as transpiration is very low – even on research farms no more than 10-30%.

This huge non-productive part can be seen as a major water resource.

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