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NEITHER WATER NOR FOOD SECURITY WITHOUT A MAJOR SHIFT IN THINKING

- A WATER-SCARCITY CLOSE-UP

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Future world food security represents a massive challenge with the solutions hidden behind inadequate concepts. Water is a major entry point and water-scarce regions are those suffering most from undernutrition, poverty and population growth and therefore represent the largest needs. In terms of implications, the situation suggests will an urgent need to realise that nothing less than a New Green Revolution is required, which targets the poverty stricken rainfed farming sector in water scarce environments. Even if successful, the achievements of a New Green Revolution will still leave large expectations on food trade and large-scale ecological consequences may be foreseen.

Water-dependent livelihood security

The Johannesburg Summit - in line with the earlier Millennium declaration - formulated targets for a successive reduction of i.a. poverty, hunger and unhealth. All these goals are in fact water-related. Unhealth alleviation is closely linked to water security in the sense of the access to safe household water (and sanitation). In water security, Swaminathan (2000) however includes also water for irrigation for poverty alleviation through production of cash crops. This means that there is a fuzzy distinction between water security for humans and water security for food production, which one might rather speak of as water-dependent security. But food selfsufficiency in arid and semi-arid regions is not equivalent to enough irrigation water. The crops really do not mind what water the roots can get access to in the root zone, whether infiltrated rainwater or applied irrigation water. When looking on the global scale almost 2.5 times more water is consumed in rainfed crops than by irrigated crops (Rockström et al 1999).

Systematizing, we may therefore conclude that the Millennium goals involve on the one hand water security for households and for employment and income raising activities such as cash crops and industrial production, and on the other food security which involves enough water to meet the crop water requirements, whether through irrigated or rainfed production.

When addressing the issue of future food production and water in the past the approach has been *predictions based on plausible assumptions* of irrigation development and probable market responses. In other words taking a forecasting approach. The problem with this approach is that it leaves uncovered a large *"hidden food gap"*, by 2020 of 360 Mton/yr, which is twice as large as projected developing country imports (190 Mton/yr, Conway 1997). There are two geographical regions in the world particularly affected by the hidden food gap, namely sub-Saharan Africa and South Asia. These two zones can be characterised by their "undernutrition climatology" in the sense that they are the two regions with the largest undernutrition and the most rapid population growth (Dyson 1994). At the same time they share their location in a semiarid zone with savannah climate characterised by distinct dry and wet seasons, large rainfall variability both in terms of intra-annual variability resulting in frequent dryspel, and in terms of inter-annual variability through, e.g. recurrent El Nino events.

If we are, however, serious with the hunger alleviation goal, a major challenge would be to try to close the hidden food gap, and if irrigation will not do the trick then other sources will have to be found. This study therefore takes a *backcasting approach*. If we want the world population in its entirety to be nutritionally well fed by, say, 2025 or 2050, what would that imply in terms of additional consumptive water use? What are the degrees of freedom? What are the main options? What are the challenges to be addressed in terms of trade-offs? The situation in the savannah zone evidently represents a global hot spot and the rapid population growth proceeding in large parts of that region - even when attention is paid to HIV/AID - shows that the situation is one of great urgency. For instance, the present drought situation combined with socio-economic and political constraints in Southern Africa implies that some 14 million people are currently threatened by severe hunger.

In this study focus will be on the additional water requirements to feed humanity one and two generations from now, and on the possible sources from which these requirements can be met. Therefore, both blue and green water has to be considered; in both cases there will be trade-offs against ecosystems, which makes the balancing a fundamental issue to approach.

Water requirements to feed humanity

The starting point for crop water needs is the fact that the photosynthesis starts with the splitting of the water molecule in the leaves; water is taken in by the roots, rising through plant vessels up to the leaves. When the plant takes up carbon dioxide - the other raw material - from the atmosphere through the stomata openings in the leaves, it looses large amounts of water as vapour, how much depends on i.a. the evaporative demand and the photosynthetic pathway of the plant.

Let us now look at how much water that will be literally consumed - vapourised - in food production on an acceptable nutritional level as seen on a *per capita level*. 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 1,300 m^3/p yr in consumptive water use, irrespective of whether the roots get the water from infiltrated rainfall or from infiltrated irrigation water. It should be observed that this corresponds to almost 70 times the basic water need on a household level, if taken as assessed by Gleick (1996) at 50 l/p d. Moreover, this human water requirement to sustain diets can be seen as more or less hydro-climatically generic, in the sense that similar amounts of water will be required to produce food irrespective of hydro-climate. Normally, it is assumed that much more consumptive water use is required to produce food in the tropics than in temperate regions. This is not necessarily the case, especially for grains, which constitute the bulk of the vegetative component of human diets. The reason is that the high evaporative demand in the tropics (resulting in a higher vapour flux from tropical crops) is largely compensated for by a more efficient photosynthetic pathway among tropical crops (C4 crops instead of C3 crop in the temperate zone) resulting in twice as high carbon assimilation per unit productive water flow (transpiration). The result is similar water use efficiencies for both temperate and tropical cereals in the order of 1,500 m^3/ton grain (Rockström and Falkenmark, 2000).

In this forward-looking approach we 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 1,300 m^3/p yr for each additional world inhabitant, but we also have to include the additional food needed to raise the nutritional level of the 800 million undernourished individuals in today's world, arriving at the following global amounts of additional consumptive water needs:

* by 2025 + 3800 km^3/yr
* by 2050 + 5600 "

The 3800 km3/yr required by 2025 is a huge amount, in fact close to ALL the water withdrawals at present, sustaining irrigated agriculture, industrial water needs, drinking, sanitation and other domestic uses. Today, irrigated agriculture represents some 70 percent of the overall water withdrawals of altogether 3900 km^3/yr, out of which 2/3 is literally consumed. Rainfed agriculture consumes more than twice as much. Moreover, huge amounts of rainwater - in fact 2/3 of all the continental rainfall - are consumed in plant production in natural and anthropogenic ecosystems (forests, grasslands, croplands).

On the regional level, Rockström (2002) identified the following increases of consumptive water needs to 2025 to properly feed the expanding population:

* Subsaharan Africa	3.1 times the present	(460 to 1450	km^3/yr)
* Asia (except Soviet)	2.2 times the present	(2830 to 6210	")

These are not only large additional consumptive water needs, but they will be required in the two regions of the world characterised by (i) largest proportion of water scarcity prone agricultural lands, (ii) highest levels of poverty and (iii) a high degree of present human induced land degradation, further deteriorating the capacity of the land to produce food.

Meeting the water requirement

Food production involves a consumptive use of the per capita amounts given above. Altered plant mass production tends to be equivalent to altered runoff generation: a land use decision is also a water decision. It may therefore influence downstream streamflow and therefore also aquatic ecosystems.

Irrigated versus rainfed production

The engineering approach to crop production distinguishes between irrigated and rainfed agriculture. It pays main interest 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. Seen in the drainage basin or catchment context, rainwater respresents the ultimate water resource, part of which vapourises as consumptive water use in plant production (socalled *green water flow*), while the rest forms runoff (socalled *blue water flow*). **Figure 1**.

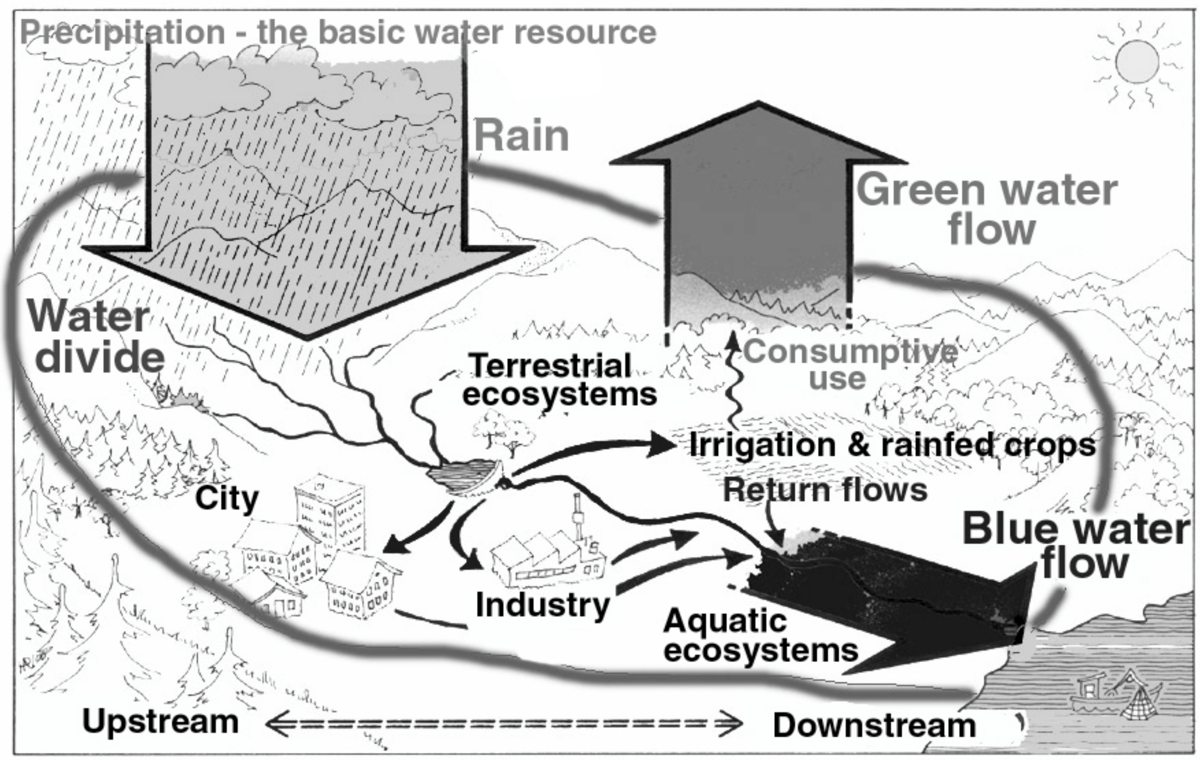

Figure 1. In a drainage basin perspective the precipitation over the area represents the proper water resource, part of which is consumed in plant production and evaporation from moist surfaces (green water flow) while the surplus goes to recharge aquifers and rivers (blue water flow), available for societal use.

There is, also 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 in the root zone, not how the water got there: whether infiltrated rainwater or applied irrigation water. The Green Revolution had its focus on irrigated agriculture. Yield levels of primary staple grains such as rice, wheat and maize, more than doubled as a result of investments in new hydrid seed and fertilisers, which made sense as water supply was secured through (i) adequate access to water and (ii) adequate purchasing power and human know-how to invest and operate small fuel pumps and irrigation schemes. Now, the challenge of a New Green Revolution stands in upgrading rainfed agriculure in water scarce tropical environments, where present yield levels, due to frequent water stress and poor land management, oscillate in the region of 0.5 – 1.5 tons/ha. Dry spell occurrence is a key constraint and an entry point for upgrading. Not only because of the yield response to bridging of water stress, but also because high risk of dry spells affects farmers risk perceptions. High risk of loosing the crop due to water scarcity means low incentive to invest in much needed soil fertilisation, hybrid seed, pest management and weeding. But by dryspell mitigation efforts rainfed agriculture can be upgraded in the tropical regions, doubling or even three-folding the yields (small scale, short-term protective irrigation based on rainwater harvesting, Rockström& Falkenmark 2000).

The global perspective: potential water sources to meet future needs of additional green water

Taking now again a global perspective, the result suggests 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 however strongly opposed by environmentalists 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. by which losses in current agricultural water use could be put to productive use, in other words transforming pure evaporation losses from wet surfaces into productive transpiration through the plant - a solution strongly advocated in the international water community debate;

* *horisontal expansion* by which green water now used for plant production by natural ecosystems (forests, grasslands), would in stead be used for production of crops.

Rockström (2002) has analysed the potential contribution from the first sources, resulting in the following possibilities to meet the water needs two generations from now, i.e. by 2050:

* irrigation	maximum	800 km^3/yr
* crop-per-drop improvements	maximum	1500 "
* horisontal expansion	minimum	3300 "

Attention needed to trade-offs involved

As just indicated, there exists a strong opposition from ecological circles against both large-scale increase of irrigation (due to negative effects on aquatic ecosystems), but also of horisontal expansion (due to effects on terrestrial ecosystems). It is evident from the sheer scale of these assessments, however, that informed tradeoffs 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 priority setting be? Let us look closer on 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 of 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 percent of the natural flow, causing the lake evaporation to take over and the lake to shrink dramatically. Through water storages, wet season flow can be stored for use during the dry season.

Improved water productivity (*crop-per-drop*) can be secured in different ways in both rainfed and irrigated agriculture. On the one hand, infiltration possibilities 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 a local stream or on its way to evaporate - 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 wells used for local water supply.

Interestingly, the largest and most immediate water productivity improvement can be achieved by increasing yield levels. Contrary to common assumptions, the relationship between water productivity and yield levels is dynamic, in the sense that every incremental increase in yield will improve the ratio of productive green water to total green water flow (i.e., the ratio of transpiration to total evaporation). This in turn will improve the water productivity, especially in the low yield range where non-productive evaporation still constitutes a large share of total vapour flow from cropped land. **Figure 2** illustrates this dynamic relationship between water productivity and yield for tropical grains grown in savannah agro-ecosystems. As seen from Figure 2, doubling yield levels from 1 ton/ha (the present average grain yield in, e.g., sub-Saharan Africa) to 2 tons/ha would result in a consumptive water saving of approximately 1000 m^3/ton.

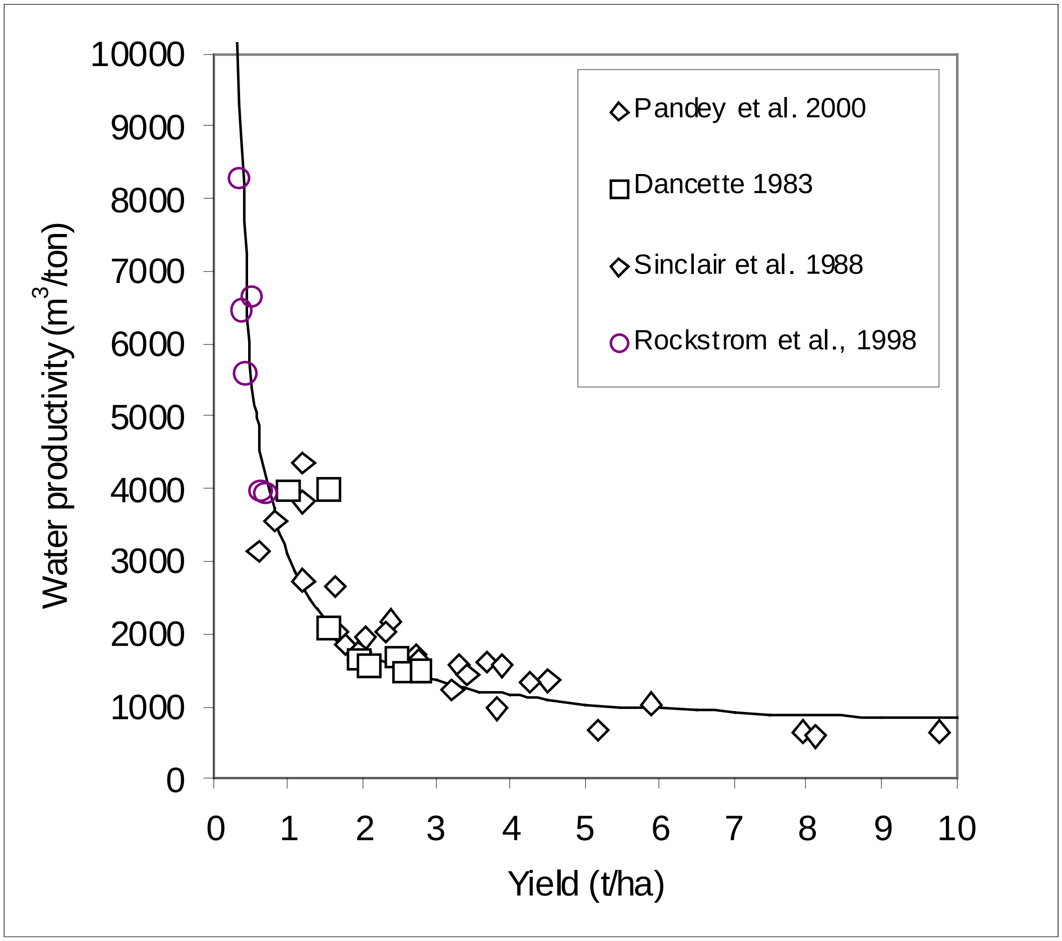

Figure 2.. Dynamics of water productivity and grain yield in tropical savannahs

Horisontal expansion, i.e. turning forested land or grasslands into croplands, involves a land cover change and 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 (socalled dryland salinisation). The hydrological consequences of replacing grasslands for croplands are more complex, however, and difficult to generalise.

The balancing needed between water for existing ecosystems and water for feeding a growing human population will evidently be a difficult one. IWMI (International Institute of Water Management) has joined a large number of other international organizations, among them IUCN (International Union for Conservation of Nature), initiating 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

<u>*Option 1: irrigation*</u>

We may now try to find out how much of these huge water requirements to feed rapidly growing regional populations that can be met by irrigation from blue water sources, i.e. by the same method that made the Green revolution possible in regions with easy access to blue water in rivers and groundwater aquifers. The regional differences of population pressure on blue water availability are quite large, both in terms of *technical scarcity*, i.e. possibility to mobilize more blue water to meet increasing demands, and in terms of *demographic scarcity* , i.e. population pressure on blue water availability or "water crowding", referring to number of individuals sharing each flow unit of blue water, **Figure 3**. Evidently, population growth increases water crowding, and therefore also dispute proneness

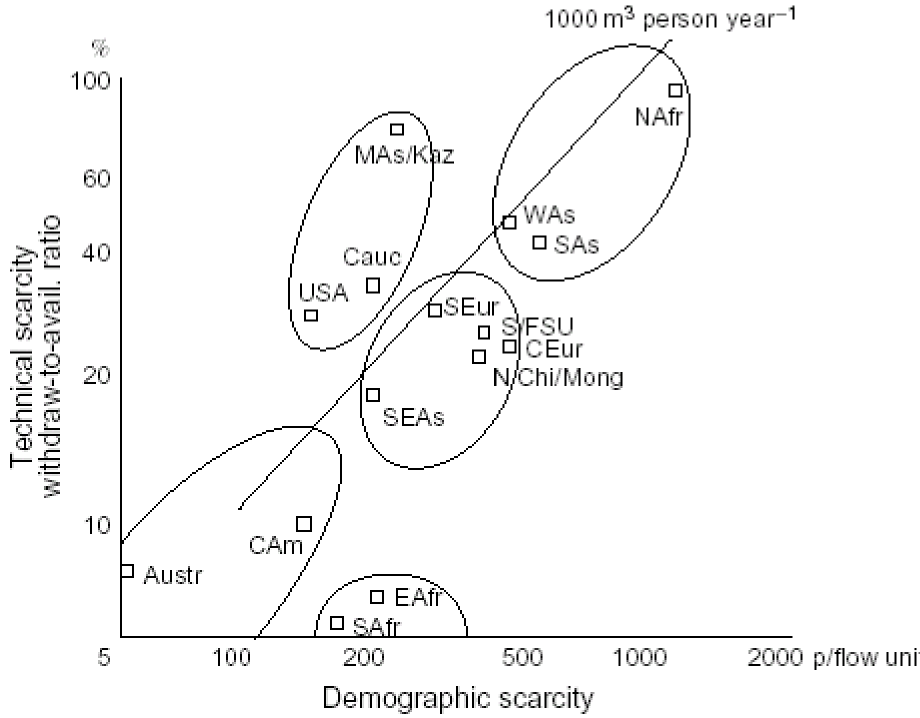

Figure 3. Regional differences between five different region clusters of the world in terms of population pressure on blue water availability (demographic scarcity, horisontal axis, people per flow unit of one million cubic meter per year) and withdrawal ratio (technical scarcity, vertical axis, withdrawal-to-availability ratio in percent). The diagonal line shows per capita water withdrawal of 1000 m3/p yr, needed for food self-sufficiency in semiarid tropics where irrigation contributes 50 percent of the crop water requirement.

Some irrigated regions are close to the 'blue water ceiling' due to high per capita water use and have limited possibilities to mobilize even more. Other regions with mainly rainfed agriculture and therefore low per capita demands are very low on the technical axis but subject to rapid population growth increasing both food needs, water crowding and dispute proneness. The diagram suggests that the two regions in the diagram denoted S As and SE As are already high on the technical stress dimension but might be able to mobilise limited amounts of more water for irrigation purposes. The opposite is true for the Subsaharan African regions (S Afr, E Afr, W Afr, the latter unvisible just below the 5 % axis). Most agriculture in these regions is rainfed. The population is pushed very rapidly towards higher water crowding levels. These regions will have very large difficulties to mobilise the water needed to support their food production needs by irrigation since they are poor in coping capability (expertise, data, financing sources).

In a river basin perspective the situation may vary quite a lot, especially in the sense of whether the basin is open or closed (Keller et al 1996). The former means that more blue water can be mobilised without serious effects on aquatic ecosystems, while the latter means that there is no more blue water that can be mobilised and put to additional productive consumptive use without serious effect on the aquatic ecosystems.

Option 2: upgrading rainfed agriculture

We have earlier made the observation that the savannah zone is the most critical hot spot as seen in a global perspective. Falkenmark&Rockström (1993) have shown that the savannah zone suffers from multiple water scarcity: A) unreliable rainfall with heavy downpours but also frequent dryspells even during wet years, B) frequent drought years due to El Nino effect, C) vulnerable soils that easily form crusts impeding infiltration, and D) low runoff generation so that small rivers go empty except during the rainy period. *Therefore, semiarid regions with mainly rainfed agriculture have particular food production challenges due to the combination of water scarcities A, B, and C and how they influence the water available to the plants in the root zone.*

They have also discussed the farmer's field dilemma (Rockström&Falkenmark 2000), finding that the water problems can be structured in three categories, **Figure 4**:

-- climatic deficiency: less rainfall than crop water requirements

-- soil deficiencies: a) infiltration problems so that part of the rainwater forms overland flow; b) low water holding capacity so that part of the infiltrated rainwater proceeds below the root zone, recharging groundwater

-- plant deficiencies: plants damaged by dryspells have poor capacity to absorb water that is in fact available in the root zone.

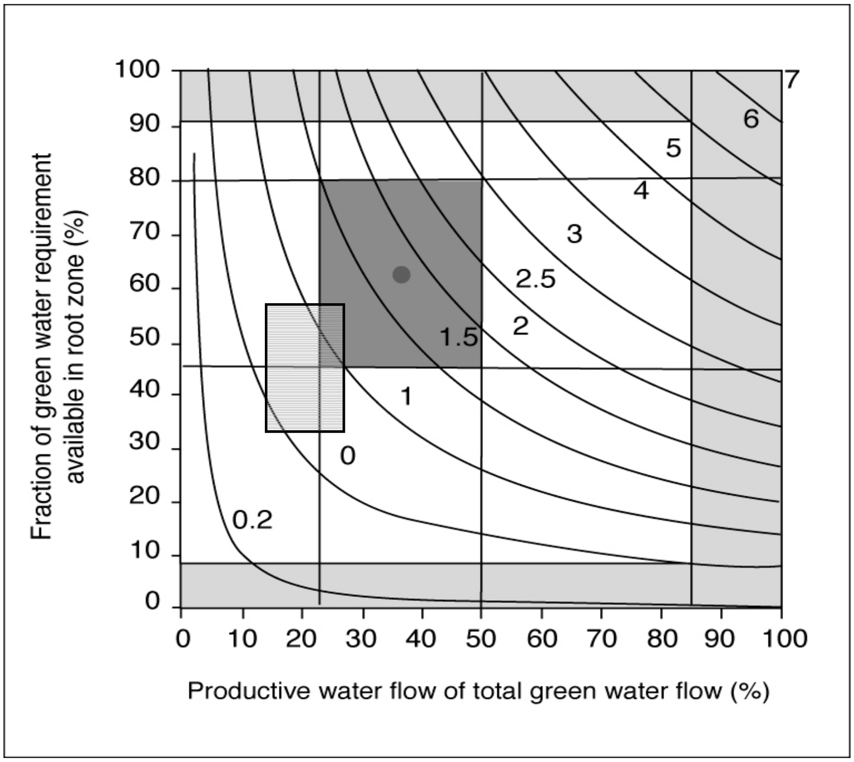

Figure 4. Analysis of the effects of rainfall partitioning and plant water uptake capacity on maize grain yields under semiarid conditions. The larger shaded area shows the range of yields experienced on average in farming systems in subsaharan Africa, the smaller shaded area the yield range on degraded farmer's fields. From Rockström&Falkenmark 2000.

They also showed that, even in the savannah zone, the potential crop yields if soil and plant deficiencies could be mitigated are of the order of 6 tons/ha whereas actual yields on the farmer's field are 0.5 - 1 ton/ha. How could this be possible, given the water related constraints? The reason is that poor distribution of rainfall over time often constitutes a larger water problem than lack of water even in dry regions, i.e., there is enough total rainfall to produce food, it is just not accessible to the roots in the right time. Wise water management can assist in mitigating water scarcity, by leveling out the periods of excess and scarcity of water so characteristic for drought prone tropical agro-ecosystems. There is in other words a *huge window of opportunity* by combining soil/water management and dryspell mitigation based on local water harvesting. Experience from India shows that supplemental irrigation of rainfed grain crops with 50 mm/ha per season, resulted in average yield increases of 90 % (Sivanappan, 1997). Research in Burkina Faso on sorghum and on maize in Kenya shows similar results where supplemental irrigation from small water harvesting systems increased yield levels with 30 – 60 % (Fox and Rockstrom, 2000; Barron et al., 1999). Combining water harvesting with soil fertility management in these experiments, resulted in yield increases of 60 – 200 %, indicating the critical need to address water and soil management together. Interestingly, in these on-farm experiments, even in the water scarce Sahelian location in Northern Burkina Faso, soil nutrient were proven to be more limiting for crop growth than water alone. The critical role of plant nutrients even in dry lands has been pointed out by several authors (Breman et al., 2001; Klaij and Vachaud, 1992)

Collecting surface runoff in water harvesting systems to upgrade rainfed agriculture has been practiced by farmers in arid and semi-arid environments for millennia (Agarwal and Narain, 1997). However, in many parts of the world, water harvesting systems have been abandoned as a result of modernisation of agriculture, especially in terms of irrigation development. In other parts of the world, such as large parts of sub-Saharan Africa, water harvesting for supplemental irrigation still constitutes innovative technologies that need to be adaptively tested and co-managed with local communities. Recently there is a new interest in water harvesting as a result of the realisation of the important role played by rainfed agriculture in efforts of achieving food security among rural poor in the future. There is at present very little hydrological knowledge on the potential of water harvesting in semi-arid tropical farming systems, and their impact on water availability for ecosystem support downstream.

Comparing the hunger gap regions

The options open for the 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, both regions with large undernutrition and rapid population growth.

In S Asia horisontal expansion is highly limited: most land is already used and there are only limited reserves of arable but still unused land. The main 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 percent of the farmers 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&Falkenmark 2000). During the transient process of social change and changing farmer attitudes in risk assessment, food import/food aid will probably have to play a central role.

A new research area appears in this connection: the water perspective of food trade, and the future flows of socalled *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 of virtual water flow to 103.5 km3/yr, which is almost 20 percent more than all domestic withdrawals (89 km3/yr, Oki 2002).

Major shifts in thinking needed

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 failure of the Johannesburg discussions of future food production should therefore cause serious concern. Already in the next generation, an additional amount of green water will be needed that is equivalent in size to ALL blue water use by humanity today. In the second generation another 60 percent will be needed.

The study has also shown that the past approach, limited to irrigated agriculture and blue water needs only, will be highly insufficient. Probably, only some 14 percent of the additional water requirements may be covered.There will in other words 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 to meet those requirements. It is no longer the irrigation needs that will remain in focus, but the overall water requirements whether met by infiltrated rainfall or supplied irrigation water. Plant production will have to be addressed by referring to both green and blue water flows.

The crop water requirements represent green water flows. But when these flows change as a consequence of land cover 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 since the evaporative demand in the temperate zone tends to be too low to generate distinguishable streamflow changes. S Africa has however started to refer to forest plantations as a "streamflow reducing activity" for which foresters will have to pay.

Although the problems are already acute, there remains a *conceptual retardness* to be overcome. This paper has shown that the green water approach is clarifying and gives an idea about the scale of the dilemma of feeding humanity and live up to the Millennium declaration. The largest immediate challenge will be to prepare conceptually for the necessary trade-offs between water for humans and water for nature.

In the new approach, agricultural engineering will have to be complemented with agro-ecohydrology. There will have to be an 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 now approaching the carrying capacity of the planet - for a long time intensively denied in broad circles?

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