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ORIGINAL ARTICLE

Shift in thinking to address the 21st century hunger gap

Moving focus from blue to green water management

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Facts are facts but perceptions guide approaches

Abstract The present water policy debate is dominated by the 30 yr old mission to secure water supply and sanitation to all people. The water needed to produce a nutritionally acceptable diet for one person is however 70 times as large as the amount needed for domestic water supply. The food security dilemma is largest in arid climate regions, a situation constituting a formidable challenge. It is suggested that an additional 5 600 km^3/yr of consumptive water use will be needed to produce an adequate amount of food by 2050 – i.e almost a doubling of today's consumptive use of 6800 km^3/yr. Past misinterpretations and conceptual deficiencies show the importance of a shift in thinking. Combining the scale of the challenge and the time scale of the efforts to feed humanity and eradicate hunger leads to an impression of great urgency. This urgency strengthens the call for international research both for supporting agricultural upgrading, and for much better handling of issues of environmental sustainability. What stands out is the need of a new generation of water professionals, able to handle complexity and able to incorporate water implications of land use and of ecosystem health in integrated water resources management. It will for those reasons be essential and urgent to upgrade the educational system to producing this new generation.

Keywords Water perceptions · Consumptive water use · Global food security · Water losses · Rainwater partitioning · Blue water · Green water · Hydroclimatic differences · Environmental sustainability · Water management

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Introduction[1]

The international water debate has tended to discuss one issue at a time. In the present water policy debate, 90 percent of the interest goes to 10 percent of the problematique (citation from A. Berntell, SIWI). What is being referred to is the dominating role in the debate of the 30 yr old mission to secure household water provision to all people. This task originates from the UN Water Conference in Mar del Plata in 1977 and its implementation has been ongoing since the start of the International Drinking Water Supply and Sanitation Decade 1980, but still remains unfulfilled.

The hunger alleviation dilemma

By concentrating so much of the policy debate on this issue, an even more daunting water-related effort tends to remain in the shadow: the water required for feeding an expanding humanity and to eradicate hunger in line with the Millennium Development Goals for 2015 and beyond. The water required to produce a nutritionally acceptable diet for one person amounts – with present level of water productivity – to 70 times as much on a per capita basis as the amount seen as needed for domestic water supply on the 50 l/p d level, often referred to as a human right (Gleick, 1996).

In spite of the lack of debate, the global food security issue is sharpening in view of a set of conflicting tendencies:

- on the one hand, food needs are increasing in order both to raise the diets to nutritionally acceptable levels and to feed the additional world population. At the same time, food consumption is moving towards more water-consuming items (meat)
- on the other hand, possibilities to expand irrigation are shrinking due to groundwater decline, streamflow depletion, and urban expansion and water source appropriation. At the same time also agricultural land is shrinking due to erosion/salinisation and to urban expansion.

This dilemma is largest in arid climate regions, where potential evaporation is larger than precipitation. This situation constitutes a formidable challenge and largely an issue of learning how to better live with water scarcity. This particular dilemma is characteristic of many of the countries with lowest human development index, referred to as top/high priority countries in the Millennium project.

The fact that this dilemma is not more discussed is quite remarkable, especially in view of the huge amounts of water involved in producing food for the growing populations in the arid climate region. Not even the water professionals themselves seem very concerned.

In the water debate, when discussing food security, countries beyond self sufficiency potential are simplistically referred to socalled virtual water trade, i.e. to import from better endowed regions. There is however to my knowledge no serious efforts to assess the potential of and implications for the export regions. In other words, where is the food going to come from, and what will be the consequences for the envisaged source regions?

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[1] This paper is an expansion of the author's contribution to the working document produced for CSD 13. "Let it reign: the new water paradigm for global food security" (SIWI, IWMI, IFPRI & IUCN 2005)

Irrigated or rainfed?

The discussions of the linkages between food production and water have until recently been limited to discussions of plausible irrigation possibilities, given an assumed market development. The problem with this approach is the gap between plausible future food production and future food requirements to achieve food security for the world population. What is left is a "hunger gap" (Conway, 1997), mainly in non-irrigated dry climate regions in Subsaharan Africa and S Asia.

Since however most of the crop production in the world takes place in rainfed agriculture, that discussion is far too limited. The crops don't mind what water is available to the roots: whether infiltrated rain or applied irrigation water. The situation therefore indicates that there has to be a shift in thinking when discussing the formidable task of feeding a growing humanity. Expanded irrigation can only solve part of the problem. Already today, there is a large scale overappropriation of river flow over 15 percent of the land area (Smakthin *et al.*, 2004). In addition there is a huge overuse of groundwater beyond the renewal rate, leading to declining water tables, more and more difficult to reach for the individual farmer. The present irrigation is in other words not sustainable. According to the Millennium Ecosystem Assessment as much as 1000 km^3/yr, out of the overall some 4000 km^3/yr withdrawn for societal water needs, is being non-sustainable.

The limited expansion potential for irrigation calls for a need to turn attention to the potential of upgrading rainfed agriculture. Earlier studies suggest a considerable potential, provided that the crops can be protected against dryspell damage (Rockström and Rouw, 1997; Rockström, 2003).

This paper will have its focus on the shift in thinking and the conceptual framework required to clarify the issue of feeding humanity on an acceptable nutritional level in line with FAO's projections. FAO foresees an average calory level in the developing world by 2030 of 2980 kcal/person day, i.e. almost 3000 kcal/person day (FAO, 2002). How much more water will have to be reserved for crop production to produce that amount of food? What has to be analysed is the net requirements in terms of consumptive water use; the possible savings by maximising "crop per drop"-productivity, i.e. reducing "true losses" and finally the potential water sources that remain by which the remaining water requirements can be met. In addition it will be essential to analyse also the *environmental sustainability aspects*: what environmental problems can be foreseen and which ones can be avoided and how? And finally – respecting the existing human right for food in an International Covenant on Economic, Social and Cultural Rights, what side effects will be unavoidable and will therefore have to be balanced against human needs by trade-off approaches?

Getting concepts right

A first condition to be able to address these issues is to have words for the different phenomena. One has to be clear about the basic truth that concepts are much more important than theories, since theories are formulated in concepts. The same holds for problem definition which means that concepts guide also the way we try to solve the problems as they have been identified.

In the scientific water community, there is for some reason an astonishingly slow tendency to update concepts and the conceptual framework that interlinks humanity and the life support system that provides human livelihoods. What will first be highlighted here are some misleading perceptions. Moreover, a set of fundamental regional differences will be discussed that are seldom being focused clearly enough, probably due to a general endeavour to keep the debate generic and not "embarrass" any particular region. By that attitude, regional particularities tend to remain in the dark and international recommendations not always be all that reliable. The reliance on the Kuznet curve is an excellent example (Arrow *et al.*, 1995; Falkenmark, 2005).

Irrigated versus rainfed agriculture

As already indicated, the issue of water and food production has until recently been concentrated on irrigated agriculture, based on addition of liquid, socalled *blue water*. Most countries in the world however depend for more that 60 percent of their cereal supply on naturally infiltrated rain, socalled *green water* (Rockström, 2001). There is also a decreasing relevance of the dichotomy between irrigated and rainfed agriculture which will have to be addressed. The concepts are increasingly difficult to separate (Rockström and Barron, 2004). In fact, one has to admit that irrigated agriculture is partly dependent on infiltrated rain. And the opposite is equally true: in the present upgrading of rainfed agriculture, small-scale farming is being increasingly supported by supplementary irrigation for the purpose of dryspell mitigation. Therefore, future development solutions tend to to be found in-between the two extremes of purely irrigated and purely rainfed agriculture. The main solutions of future agriculture will be different forms of in-between varieties.

Water losses

Since so much attention currently goes into finding out the implications of reducing water losses in low efficiency irrigation systems, through efforts to increase the amount of crop produced per drop of water, the concept water *losses* has to be properly clarified. In its present use, it is diffuse and partly misleading. On the one hand, it may refer to blue water losses from canals and irrigation fields that return to the basin and can be reused. On the other hand, it may refer to green water losses in terms of pure non-productive evaporation losses from canals and from irrigation fields. What we need is therefore to get a clear picture of what are '*true*' as opposed to '*imaginary*' losses in agriculture. On a catchment scale, it is only the green water losses which are true losses, while the return flows are only imaginary losses.

Also the concept *water use* is diffuse. It often refers to water withdrawals, irrespective of whether part of that water is going back to the water system after use as *return flow*, or it is turned into *consumptive water use* and vanishes from the area. For instance, (Shiklomanov, 2000) has assessed water withdrawals for municipal, industrial and agricultural uses to 3900 km^3/yr, out of which only 1800 are being referred to as consumptive water use. In order to avoid double-counting, focus should be given to the consumptive water use of irrigation water, rather than the amount withdrawn from the river, since it implies *a blue-to-green redirection* of the water flow, that will basically involve a corresponding depletion of the streamflow.

Rockström *et al.* (1999) has estimated the consumptive/depletive water use involved in current food production at 6 800 km^3/yr, out of which some 1800 originates from irrigation (blue-to-green redirection), whereas 5000 originates from naturally infiltrated rain. Applying today's crop water productivity, consumptive water use in agriculture includes *avoidable losses* in the sense of water use beyond the biologically controled transpiration needs, or "unnecessary" evaporation, amounting to maybe one third of the 6 800 km^3/yr or about 2300 km^3/yr, a sizeable amount.

Some regional particularities

Differences in hydroclimate are reflected in large differences in terms of both human livelihood and dominating vegetation patterns (Falkenmark and Chapman, 1989). A factor of dominating importance is the evaporative demand of the atmosphere and how it relates to precipitation. In fact, precipitation over populated agricultural regions in the temperate climate zone does not differ very much from the situation in corresponding areas in the tropics. What is different is the evaporative demand (Falkenmark and Lindh, 1976).

The implications are illustrated for three different hydroclimatic situations in Figure 1 (Falkenmark and Rockström, 2004)

- the temperate region is least complicated, as there is enough precipitation, moderate evaporative demand and therefore a precipitation surplus left to generate runoff
- in the semiarid tropics, the rainfall is similar but the evaporative demand returns almost all rainfall to the atmosphere, leaving only a minimal amount to generate runoff. This complicates irrigation in areas devoid of rivers entering from remote mountain regions
- in the humid tropics, both rainfall and evaporative demand are high but there still remains a large surplus generating runoff.

Although the semiarid tropics are characterised by highly vulnerable ecosystems, they combine at the same time rapid population growth, poverty and land use as a base for life support. They can therefore be seen as the global hot spot region in terms of hunger alleviation challenges. Although they are often rather misleadingly referred to as 'marginal drylands', the term *savanna* better reflects the fact that these drylands are not as dry as often perceived (Falkenmark and Rockström, 2004): there is basically rainfall enough to support crop production during the wet season. *Many of the top/high priority countries highlighted in the Millennium Project are in this region.*

Poorly adaptable ecological concepts

There is finally reason to address the issue of environmental sustainability and the concepts involved. Basically, ecological concepts are based on biological phenomena while hydrologists – in order to enter attention to vital ecosystems in their water management efforts – need to put focus on the water determinants of the ecosystems (Falkenmark *et al.*, 2003; GWP, 2003). For hydrologists, *terrestrial* ecosystems where the soil moisture is a key determinant have to be properly distinguished from *aquatic* ecosystems for which the water in the river is the determinant. *Wetlands* – although hydrologically quite different – all combine a biological meaning in the sense that the soil is wet and oxygen free (Pielou, 1998). They may however differ considerably in terms of the type of water that keeps the wetland wet: condensation, rainfall, soil moisture, groundwater discharge, inundating surface water, streamflow, etc.

Water requirements to feed tomorrow's humanity

Forecasting versus backcasting

Past studies on future relations between water and agriculture have tended to have their focus on irrigation. They have started from projections of plausible food consumption needs, paying attention to an assumed income growth and market development, and analysed how those needs could be met by an increased food production (FAO, 2003; Rosegrant *et al.*, 2002).

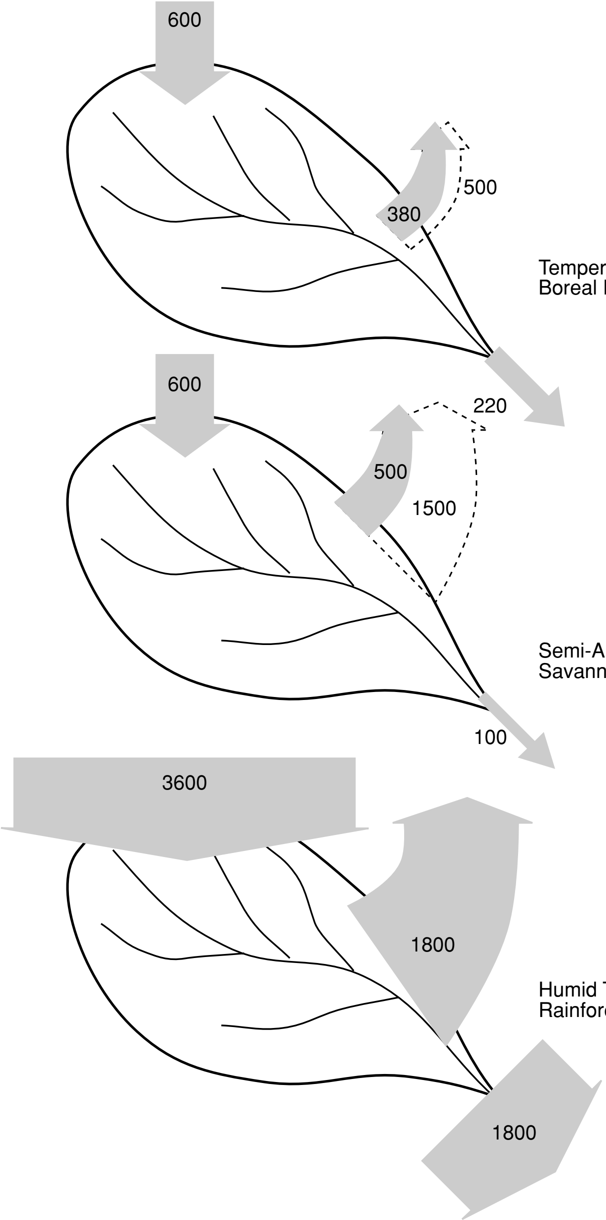

Fig. 1 Differences in water-related livelihood determinants (precipitation, potential and actual evaporation, and runoff generated). Comparison for three ecological regions based on data from Lvovich

It has however been revealed that even if foreseen food consumption needs will be met, the result will not be food security, due to a remaining "hunger gap" in poor regions (Conway, 1997).

Assuming that the international ambitions to alleviate hunger and undernutrition as reflected in the goals of the World Food Summit in 1996 and in the MDG's are serious, it is possible to take the opposite approach: to estimate what consumptive use will be needed to feed humanity as a whole on an acceptable nutritional level and to estimate what would be the freshwater implications. In other words taking a *backcasting approach*.

Additional consumptive use requirements

Both Gleick (2000) and Rockström (2003) have analysed the consumptive water use involved in producing today's diets. According to Rockström, they amount to 690 m^3/p yr in Subsaharan Africa and 820 m3/p yr in Asia (except the former Soviet Union). He has also shown that to produce a diet of 3000 kcal/p d, which is the average nutrition level in developing countries foreseen by FAO by 2030, will correspond to a consumptive use of 1300 m^3/p yr (including 20 percent animal protein).

Combining these data with population increase as foreseen til 2050 AD – when world population is expected to have more or less stabilised – suggests that to produce the food needed on the one hand for raising the regional diets to this level, and on the other to feed the additional population, *we can foresee the need for an additional consumptive water use for food production of altogether 5 600* km^3/yr (Rockström, 2003) – assuming no change in water productivity. This is almost a doubling from the current 6 800 km^3/yr. Comparing the regional freshwater needs with current consumptive water use in the two hot spot regions indicates that for food selfsufficiency, Subsaharan Africa would need to increase the consumptive use by a factor 3.1 (from 465 km^3/yr to 1450) and S and E Asia by a factor 2.2 (from 2830 km^3/yr to 6210).

There are of course numerous options to find these additional amounts of water that will have to be appropriated from other current uses by humans or by ecosystems (Figure 2). The first option is of course *to increase water productivity* by reducing true losses, i.e. transfer non-productive evaporation into productive transpiration (maximise crop per transpired drop by vapour shift).

Rockström (2003) has assessed the different options as follows:

- *loss reduction*, in irrigated agriculture maybe 200 km^3/yr, in rainfed maybe 1500 at the most
- *additional irrigation*, to be limited due to the streamflow depletion that might follow – scarcely more than 600 km^3/yr

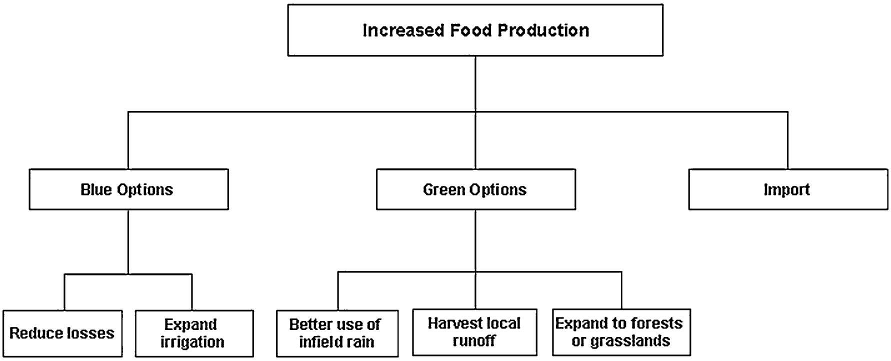

Fig. 2 Three basic ways to capture the additional water needed to meet consumptive water use of increased food production: blue water options, green water options, and import/virtual water option

- the rest or 3 300 km^3/yr will have to be covered by *expanding rainfed agriculture* into forests and grasslands, by *import from cooler areas* (saving maybe some 400 km^3/yr, Oki and Kanae, 2004), or by altering the water requirements of the crops through *biotechnology* influencing the time to ripening etc.
- reducing the consumptive demands by *diet changes*, basically covering the highly water consuming meat component by less water demanding protein sources (soya beans, etc.).

Implications of current environmental degradation

Living with change

The task to mobilise the water needed to meet the water requirements discussed above, to feed the growing humanity and alleviate undernutrition evidently involves large changes in terms of both land use and water partitioning into green vapour and blue liquid water flows. These changes will all have ecological consequences which will be the price to be paid for food security. A crucial challenge for humanity will therefore be to find out how to live with change while protecting environmental sustainability. And what should be meant by environmental sustainability?

First of all, it will be essential to try to get out of the current environmental degradation, caused by today's non-sustainable agricultural practices. There is in fact a large scale undermining of the biophysical resource base going on in the world. It has moreover to be realised that some of the undermining phenomena are *unavoidable* (streamflow depletion due to reduced runoff generation or consumptive use of irrigation water; clearing of new croplands), whereas others are at least theoretically *avoidable* (groundwater overexploitation, nutrient leaching, and land productivity decline by erosion and salinisation).

Especially critical for future food production is the current overdraft beyond acceptable blue water withdrawal quantities in rivers and aquifers. Such overdraft involves not only the *loss of water sources in current use for irrigation purposes,* but limits also the possibility to expand irrigation withdrawals.

Reduction of river flow

The consequences of large consumptive use in irrigation-dependent areas is a widespread streamflow depletion through the blue-to-green redirection of the water flows involved. These consequences are particularly troublesome in socalled closed river basins, where the remaining unappropriated flow has to be protected for the aquatic ecosystems (Lannerstad, 2002; Falkenmark and Lannerstad, 2005).

Ecologists have estimated the minimum water flow required for aquatic ecosystems at some 30 percent of the annual flow, for regions where there is a dry season to which biota are already used (Smakthin *et al.*, 2004). In a recent world overview these authors estimate, as already indicated, that over altogether 15 percent of the land area, hosting some 1.4 billion people, is streamflow already overappropriated. River depletion implies a reduced river flow relative to the long term average, in some rivers even a change from perennial to intermittent flow. Reduced flow involves also reduced wastewater dilution capacity, and of course sharpens the conflict of interest between upstream and downstream water uses.

The most evident example of river depletion. is the tributaries to the Aral Sea, where the result gets particularly evident since the Aral Sea is a closed lake without outlet (Falkenmark and Lannerstad, 2005). The only way the lake can respond to a reduced inflow is by evaporation in order to diminish the lake surface, until there is balance between the evaporation from the shrunken surface and the new inflow. The Yellow river is another example where the mouth first dried up in 1972, continuously increasing so that by 1997 it was dry for altogether 7 months with the dry-up reaching 700 km upstream.

Groundwater overexploitation

Also the groundwater overdraft is cause for concern (Foster and Chilton, 2003) since it indicates that a non-sustainable source of water is being consumed for irrigation, a source that will no longer be available in the long-term. Rosegrant *et al.* (2002a) estimate groundwater overdraft beyond groundwater recharge to 200 km^3/yr, with India, China and USA as the major groundwater depleting nations. Seckler assessed a quarter of India's harvest to rely on such overdraft (Shah *et al.*, 2003).

Unless reduced to sustainable levels, present groundwater use in NE China will effectively destroy the groundwater dependent agriculture base, cause massive subidence and sea water intrusion, and involve the loss of 'insurance' water for the future generations (Chinese Ministry of Water Resources in Moench *et al.*, 2003).

Nutrient leaching and eutrophication of surface water bodies

Leakage of the nutrients N and P from agricultural systems is causing major environmental problems at present. It is estimated that only about half of these fertilisers are captured in harvested crops (Tilman *et al.*, 2001). Should current trends continue in terms of global N-fertilisation, this would add 60 percent more fertilisers by 2025 and 170 percent more by 2050.

One consequence of the large scale leaching of N from areas where groundwater is being recharged is rising nitrate levels in groundwater, a phenomenon widely spread under agricultural regions in for instance Europe (Vogel and Grath, 1998). In semiarid climates with low groundwater recharge, even small losses of N are enough to rise to high concentrations of nitrate in groundwater (professor G. Jacks, personal comm.). Not only commercial fertilisers but also use of large amounts of manure involves high risk for large leaching losses.

Consequences are widespread also in surface water bodies where they are easily detectable in ecosystem switches with time, through the generated eutrophication problems. In the long term the bottom waters develop oxygen free conditions, like in the Baltic Sea, the Black Sea and the Mexican Gulf.

Reduction of land productivity

Over 80 percent of arable land worldwide is affected by soil degradation, reducing its productivity (Millstone and Lang, 2003). Contributing factor in the tropics has been population growth and the related collapse of the fallow-based production system of shifting cultivation. While an *erosion* of 10 tons/ha yr is considered an absolute limit for sustained agriculture, erosion in semiarid tropics with intense seasonal rains may be three times as high (Jacks, 2004).

An important determinant of land productivity is the *nutrient* level in the soil. While in many industrialised countries, due to high level fertiliser application, nutrients are accumulated in soils, building up pools of "chemical bombs" (Hekstra, 1995), there is the opposite situation in Africa where a kind of 'soil mining' is ongoing. This is due i.a. to the reduction of fallow periods forced by population growth, not compensated by addition of the nutrients needed, following the example of regions in the industrialised world when going into continuous agriculture (Falkenmark and Rockström, 2004).

Moreover, semiarid tropical countries are highly vulnerable to altered land use due to the changes generated in terms of the consumptive water use. When runoff generation is low, even moderate changes in green vapour flow may be reflected in alteration of runoff that may be large in a relative sense. Such changes have been generated in Australia which now suffers from serious *salinisation* problems caused by the land use change during the immigration period, when the eucalyptus woodlands were cleared for crops and grazing (Gordon *et al.*, 2003). These transitions generated water logging and salinisation of both soil and groundwater, and now adversely affects agricultural and pastoral yields. The damage now encompasses some 3.3 Mha. Some 5.7 Mha are considered at risk, predicted to increase further to 17 Mha in 50 years time.

Salinisation is a widespread problem also on irrigated land when there is absence of appropriate drainage, especially under excessive irrigation. Such absence is usually due to the large expenses linked to digging of drainage canals. According to WWAP (2005), poor drainage and irrigation practices have led to waterlogging and salinisation of approximately 10 percent of the world's irrigated lands.

The environmental protection challenge

In order to minimise the ongoing undermining of the resource base it will have to be clarified what the criteria are for "environmental protection" and "protection of ecosystems". Protection from what? To achieve what? First of all, the word ecosystem carries no scale, which leads to the question what scale of ecosystems that we are referring to: a particular component of the landscape regarded as an iconic site, a biodiversity reserve etc., or the catchment as a whole seen as an ecosystem (GWP, 2003).

A key function to secure for future generations is the capacity of the life support system to deliver food and biomass, ecological services of various kinds while enduring disturbances and variability without shifting to a non-desirable state of the system (Gordon, 2003), for example unproductive soils, savannisation of the rainforest, collapsing farming system, eutrophication of a lake etc. Ecological systems in the landscape are linked by flows of water in an upstream/downstream pattern. Freshwater flows, crop production and other terrestrial ecosystem services are interconnected and interdependent. Aquatic ecosystems downstream respond to the integrated result of all upstream acvtivities.

One way of seeing the linkage between integrated water resources management and ecological services is to manage catchments as an asset that delivers a bundle of water and ecological goods and services (GWP, 2003). Some of these services work in synergy, others in conflict. Criteria have to be developed for the protection of the capacity for sustainable production of life support, i.e. identification of what key functions are essential for the production of terrestrial and aquatic ecosystem's goods of social and economic importance, and terrestrial and aquatic ecosystem's services of ecological importance from different aspects. Humanity, through its activities tends to alter disturbance regimes with which organisms have evolved over time. There is therefore a need to secure enough "elasticity" (resilience) of ecosystems to change in the surrounding conditions like storms, fire, drought, pollution events, or creeping pollution. What has to be protected is the capacity to absorb continuous change without loss of the dynamic capacity of vital ecosystems to uphold the supply of ecological goods and services.

As pointed out by Gordon (2003), freshwater redistribution may reduce resilience of ecosystems in two main ways: both through a change of the role of freshwater as an internal *structuring variable* (water quantity and quality), and as a *disturbance regime* (temporal variability and timing). Land use and land cover change that alters the fluxes of water to and from the soil can change the soil moisture at a local scale. Land cover change that modifies the fluxes of water to the atmosphere can cause effects on scales, ranging from local to global. Ecosystems may have multiple equilibrium and internally changing variables within the system, like changes in quality or quantity of freshwater, reducing its resilience and causing a transition from a desirable to a non-desirable state.

Towards food production sustainability

Main challenges

It is evident from the above that global food security is an enormous challenge not only in terms of today's weakness – food distribution – but in terms of the water implications if FAO's projections of food consumption by 2030 would materialise. It has already been shown that producing the food needed to reach a world nutrition average of 3000 kcal/p d – because of the consumptive water use involved – would have major water implications. One has to consider the problematic fact that on the one hand river flow is already overused in many of the irrigation-dependent regions (15 percent of land surface), and on the other there is a large scale use of non-renewable groundwater over essential food producing regions in India and China.

Groundwater overexploitation has to stop before it leads to foreseeable societal collapses when the water source for irrigated agriculture gets out of reach. Such calamities will be unavoidable in heavily groundwater-dependent regions in India and NE China. Where groundwater use cannot be controled in time due to millions of farmers like in India (Shah *et al.*, 2003), an agricultural restructuring will be unavoidable towards upgraded rainfed agriculture supported by protective irrigation, especially during dryspells, and based on water harvesting, or close to cities on reuse of recirculated urban wastewater.

This basically means that future food production will have to benefit maximally from rainfall rather than from irrigation. As already indicated, climatic data show that there is, also in the semiarid regions, generally rainwater enough during the rainy season to meet consumptive water requirements from one crop, provided that the roots get access to that water and plants can be protected from dryspell damages (Rockström and Falkenmark, 2000).

Since the approach taken here is based on today's water productivity, considerable reduction of water requirements would be possible by reducing water losses. Primarily, it will be essential to maximise productivity per drop of water transpired, i.e. minimise evaporation losses. Productivity increase is in other words equivalent to loss reduction or "regaining" the water involved in evaporative losses to cover part of the additional consumptive water use (Falkenmark and Lannerstad, 2005). Minimising runoff losses is a more complicated issue, since these losses are no true losses but form blue water flows available elsewhere.

At the same time, attention has to be paid to the fact that today's agriculture is undermining its own resource base. A sustainable future agriculture therefore implies mitigation of avoidable problems linked both to land productivity (nutrient leaching, erosion, salinisation) and to water productivity (groundwater overexploitation), Figure 3.

But it also involves acceptance of streamflow depletion as a principal consequence of on the one hand reduced runoff generation as a result of land use alteration, and of on the other hand blue-to-green redirection of water withdrawn for irrigated agriculture. Also loss of terrestrial ecosystems will have to be accepted where necessary to alleviate hunger and no other alternatives remain.

Key measures needed to make agriculture more environmentally sustainable involves in other words two categories of management activities: on the one hand *mitigation* of avoidable problems or at least ceasing to aggravate them, and on the other hand balancing conflicting land and water interests by *trade offs* in regard to the risk of further streamflow depletion or lack of alternatives. When situations have already gone too far in terms of river depletion, the first step may be to buy back allocated irrigation water from irrigated farms in the way that is now practised in Australia (Scanlon, 2004).

Water management implications

On the most general level, one can say (Falkenmark and Rockström, 2004) that a successful management will have to incorporate efforts to

- *secure* water and related services, in this case water-dependent food production
- *avoid* degradation of water and land resources and of ecosystem integrity
- *foresee* changes (climate, population, diet preferences etc).

To achieve this, an integrated approach will have to be taken to blue and green water, seeing precipitation as the basic resource, and to water quantity and quality (GWP, 2003). The best way will be to benefit from present focus on integrated water resources management (IWRM) on a catchment/river basin basis (blue water approach) but to incorporate green water through its interaction with the blue water, Figure 4. This would lead to an integrated land and water resources management (ILWRM). Efforts towards such management approach is being practised in several transnational rivers supported by the Global Environment Facility (Duda, 2003).

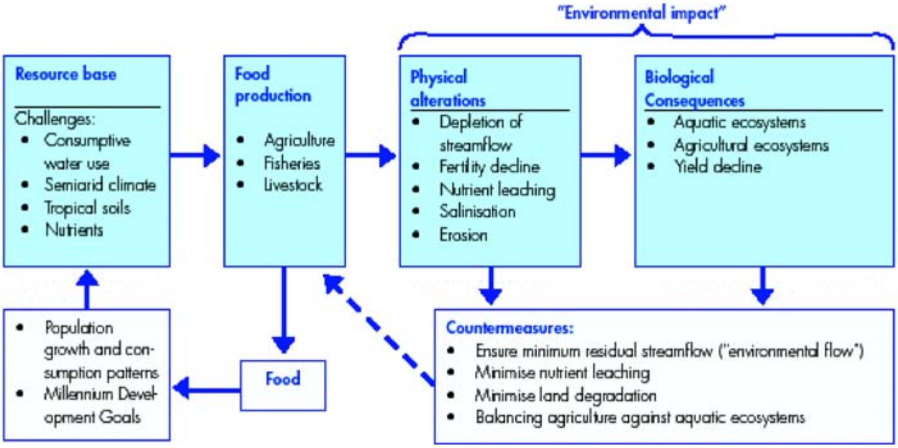

Fig. 3 Links between food production to meet global food needs, environmental impacts generated by agricultural practices, and possible countermeasures towards ecologically sustainable food production

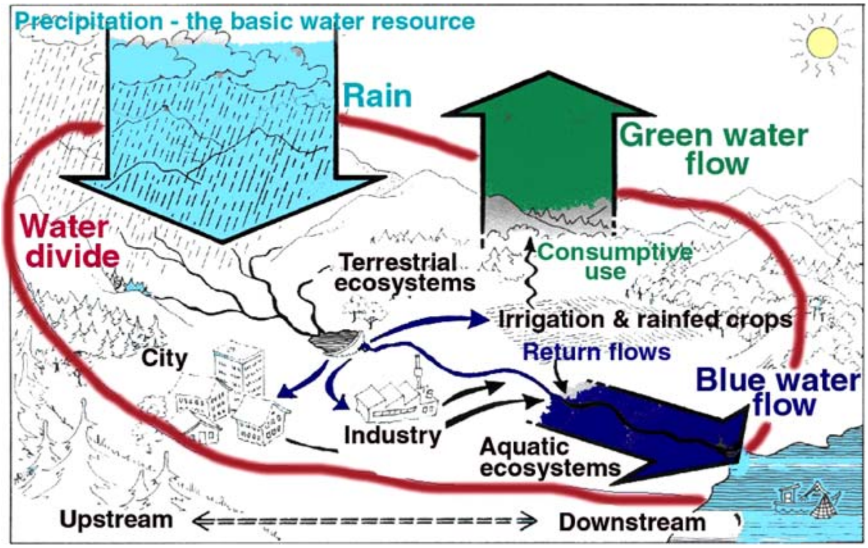

Fig. 4 The catchment allows an integrated approach to all water-related phenomena within the water divide. All the rain falling within the water divide is being partitioned between humans and ecosystems, terrestrial as well as aquatic; between land use and water; and between upstream and downstream

Minimising ecosystem degradation will involve both water pollution abatement to protect the habitats of aquatic ecosystems, and securing minimum streamflow ("environmental flow"). Minimising nutrient leaching and land fertility decline will be a major part of management efforts. What it all boils down into is an *integrated land/water/ecosystem approach*.

Catchment routing

Taking a truly integrated land/water/ecosystem approach will demand a stepwise routing procedure with water accounting (GWP, 2003) – stretch by stretch – down the catchment, or conversely from the river mouth up to the water divide (FAO, 2000). Attention has in each stretch to be paid to runoff added to different river stretches by runoff generation from surrounding land; to water demand sites and withdrawal needs; to pollution sites and amounts added; assessing consumptive water use involved, return flows, available amounts of dilution water and water quality implications.

The process has to pay adequate attention to upstream/downstream relations, resilience criteria both for iconic ecological sites and for downstream aquatic ecosystems, and to related bottom lines in terms of downstream streamflow (GWP, 2003). In the analysis, value routing may be useful to guide in the necessary trade off striking (Falkenmark and Rockström, 2004). Throughout the process, social acceptability will have to be secured through a legally achnowledged stakeholder participation in the trade off process.

Conclusions

FAO foresees a rapid improvement of diets with calory levels increasing to an average for the developing world of 3000 kcal/p day in 2030. What will be needed to complement these studies is an analysis of the water implications; this paper has given a first idea about the unbelievable scale of feeding humanity on the foreseen calory level and with 20 percent animal protein. It is difficult to deny that attention has to be paid to biophysical constraints and trade off challenges when analysing the implications of the hunger alleviation, linked to the conception of human right to food. In terms of the most extreme consequences, it suggests that FAO's nutrition projections would bring on the choice between cutting down even more tropical rainforests or reducing the meat content of tomorrow's diets.

In view of the weight of the goal of feeding humanity and alleviating hunger, the water implications discussed above motivates major international attention, especially in view of the choices involved and the environmental sustainability dimension. The challenges should be seen as issues of evident significance both for research and for policy development. An evident occasion to bring up the issue will be the Millennium Summit in September 2005, but there the attention will probably be concentrated on the 2015 MDG-targets, i.e. the near term future.

This paper has also demonstrated the complexity of the issue of feeding humanity already when seen in a natural science perspective only. To that complexity has to be added societal and economic complexities.

Furthermore, past misinterpretations and conceptual deficiencies show the importance of a *shift in thinking* to make it possible to address the complexity. The water community has to get out of the "eddying discourse" that now characterises the international policy debate. This debate tends to circulate around a limited number of issues – however important: water supply and sanitation, privatisation, dams etc. What is neglected is the water-related implications of the very basic issue of human right to food.

The scale of the challenge and the time scale of the efforts to feed humanity and eradicate hunger, gives an impression of *urgency*. It is quite remarkable that such urgency does not characterise the general debate. This debate continues more or less along the lines of the 1980's and 1990's. This urgency strengthens the call for international research both for supporting agricultural upgrading, and for much better handling of issues of environmental sustainability.

What also stands out is the need for a new generation of water professionals and hydroecologists, able to handle complexity and able to incorporate water implications of land use and of ecosystem health. It will for those reasons be essential and urgent to upgrade the educational system for producing this new generation.

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