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Interactive comment on "Consumptive water use to feed humanity - curing a blind spot" *by* M. Falkenmark and M. Lannerstad

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The authors have much appreciated the opportunity that HESS-D has provided to carry out an interactive discussion of our manuscript "Consumptive water use to feed humanity - curing a blind spot". Special thanks are due to valuable comments by A. Montanari and P. van der Zaag, which we respond to in the following.

RESPONSE TO MONTARAI'S COMMENTS

Excessive pessimism of authors relative to FAO-study "World Agriculture: Towards 2015/2030" The fundamental difference between the two approaches is that FAO's study is a projection to 2030 based on foreseeable changes in food consumption and production, showing that those needs can be met. There is however no analysis of the water implications, and no estimates of green water flows from rainfed agriculture. Our study is a back casting that aims at demonstrating the water implications of taking seriously the need to feed humanity on an acceptable nutritional level (3000 kcal p^{-1} d^{-1}

as predicted by FAO as an average for developing countries by 2030, out of which 20% animal protein). In our study this calorie level was applied also for 2025. In the paper we stress that there should be a distinction between supply to a certain water use (often called consumption, withdrawals or diversions) and the actual consumptive water use by a water activity (evapotranspiration or green water flow). Additional green water requirement estimations for 2025 (3800 km^3) and 2050 (5600 km^3) are based upon today's water productivity and agricultural production context. The quantities should thus be regarded as an alert of the magnitudes of water quantities and water productivity increases needed in irrigated as well as rainfed agriculture. Our calculations in section 4.2 are an attempt to estimate where to find the additional consumptive water needs for future food production quantified to 3800 km^3/yr and 5600 km^3/yr.

FAO projections (FAO 2003, p. 140) are largely based upon arable land estimates and focus on 93 developing countries. Estimations of water resource use in agriculture only refer to irrigation. In 1997 water withdrawals were 2128 km3/yr and by 2030 estimated to 2420 km^3/yr, or a 14% increase. Since irrigation efficiency during the same period increases from 38% to 42%, this increase corresponds to a rise in consumptive water use in crop production of 26% or 207 km^3/yr - an increase almost twice as big. No estimates of green water flows from rainfed agriculture are however given, but FAO anticipates an expansion of rainfed harvested area by 15%, to 834 Mha, and net area by 11%, to 722 Mha.

Since starting point in our study is today's water productivity, productivity increases come out as regainable water that can cover part of the additional water requirements. Increasing the water productivity will evidently depend on changes in agricultural practise. The capability to reduce water needs is reflected as water not needed but "regained" for use elsewhere. FAO looks only on regaining irrigation water (240 km^3/yr). Our assumption is that of the total amount regainable, 200 km^3/yr could be gained in irrigated agriculture by water productivity increase, in other words the same order of magnitude.

Potential for further irrigation development: this is being addressed by reference to the diagram in Figure 5 which shows the degrees of freedom to increase water withdrawals given necessary attention to protection of remaining streamflow for aquatic ecosystems (environmental flow).

Rice, maize, feed protein, conversion efficiency and consumptive water use

As pointed out by Referee Montanari FAO (2003) describes a trend of conversion of rice/paddy to maize/corn in China. This confirms Rosegrant's scenario assumption discussed in section 5.3. Such development is indeed important from a consumptive water use perspective. Rice is a staple crop for human consumption while maize in many countries to a large degree is used for feed to meet the increased demands for meat and for industrial use. In 2002/03 76% of domestic maize use in China was used for feed (USDA, 2004). Current trend of increasing meat demands and industrial use will likely soon turn the country into a significant maize importer active on the global market (Bange, 2004). A rice to maize crop change can thus be viewed from different angles. Montanari states that rice has consumptive water use twice the quantities needed for maize. A conversion of feed calories to meat with an efficiency of 2 to 1 would mean equal consumptive water use, if less efficient more water is needed and if more less. When analyzing consumptive water use in national, regional or global perspectives green water flow quantities in agriculture, food and industrial crops, must be related to the consumption per capita and for the entire population, not per hectare. Generally a conversion from vegetarian to meat diet means increased consumptive water use. If a part of the maize production is used for industrial uses, e.g. ethanol production, food, e.g. rice, must be produced with additional water some other place.

Climate change

Climate change has not been taken into account in our study. Climate change effects are a question of time and scale: it appears to be difficult also for experts in this field to quantify and geographically locate changes in precipitation and evaporation. Most certainly climate change will influence global, regional and local hydrological cycles and

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the distribution of precipitation that follows increases and decreases in evapotranspiration. Some research indicates that the occurrence of extreme weather conditions is increasing. If so, this will increase the difficulties for successful agricultural production in many areas. Sub Saharan Africa is especially vulnerable in this respect since this area is already suffering from recurrent drought years and dry spells.

Influence on climate by green water flow increase: The destiny of the evaporated water has not been discussed due to our focus on consumptive water needs. There are however studies on the effects of green flow alterations: from deforestation both on the Sahel region drought by Savenije, and in terms of the savannisation of the Amazon basin by Werth and Avissar.

Minor comments

- Ambio: The observation is aimed at catching the general feeling in the international debate that water is getting scarcer. As we see it water quality is an attribute to water availability which influences the usability, not the availability

- Reuse of return flows: We agree that the return flow will not necessarily be simple to reuse. It will nevertheless be somewhere in the basin, unless drained directly to the sea.

- Spelling correction: Correct spelling of the referenced Russian hydrologist is L'vovich.

- Forests: the view in the Millennium Ecosystem Assessment that forests are water provisioning has been criticised in the review phase. From an ecohydrological perspective forests are water-consumptive rather than water provisioning. They are however water regulating in the sense that forestry activities hit the rainwater partitioning at the ground and therefore influences runoff formation, groundwater recharge and dry season streamflow. The atmosphere is responsible for the water provisioning of the continents.

- Aral Sea: this is an excellent example of the consequences of river depletion since it is

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a closed lake. The cause of the depletion is agricultural activities seen as beneficial for the upstreamers - the basis for the economic development there. But the downstream effects are disastrous for the downstreamers in the basin.

- C3 versus C4 plants: C3 and C4 are two different metabolic pathways associated with the photosynthesis fixation of carbon dioxide. C3 plants use the C3 photosynthetic carbon reduction (PCR) cycle, while C4 plants also use the C4 photosynthetic carbon assimilation (PCA) cycle. In drier and hotter climates this enables the C4 plants to be more water efficient compared to C3 plants and decreases the water vapour loss through the stomata when assimilating carbon dioxide (Taiz and Zeiger, 1991). Examples of C4 plants are: maize, sugarcane, sorghum and several other grasses.

- Environmental flow: The study by IWMI, IUCN, WRI and University of Kassel involves differences between temperate and tropical regions. The key difference is to what degree natural ecosystems are used to a dry season or not. This explains the lower value for the tropics (30%) as compared to the temperate region (50%).

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Graph Figure 6

The original graph has a blue water perspective, or should we say, a river depletion focus. We much appreciate the comments from van der Zaag and his elaboration of the figure with a basin water productivity perspective, distinguishing the alterations and relative importance of transpiration and evaporation, i.e. "vapour shift".

Since also a part of the non-transpiration evaporation originates from irrigation it is however necessary to have two basin figures (or one aggregate combined): one that displays the origin of green water flows and how human activities decrease or increase the blue water outflow, and one that puts the relation and alteration of "transpiration" (productive) and "all evaporation minus transpiration" (non-productive) in relation to the partitioning of basin precipitation into green and blue.

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We are well aware of the concept "white water" coined by Savenije. We have concentrated on the original concepts "green" and "blue" water to keep focus on the links between land and water management and to include also the vapour flow from vegetation and different surfaces. The green-blue approach has been an eye opener during the last decade. By introducing additional colours, e.g. white, brown, grey, black, golden or red, the fundamental message in the green-blue approach would be weakened.

Missing conclusion

Van der Zaag suggests the conclusion that it is better to increase crop yields than to expand horizontally to new arable land. Our study shows that loss reduction will only contribute 2250 km^3/yr out of 5600 km^3/yr needed, i.e. less than half of what is required to feed the world population by 2050 on a 3000 kcal p^{-1} d^{-1} diet. We however agree, that in a particular region, it is of course wise to start with productivity increase.

Van der Zaag points out that the manuscript could have stressed the importance of fertilizers, and other agricultural inputs or technique improvements, to increase the density of biomass. We have understood that such factors are necessary to attain water productivity increase.

Meat involves a more water consumptive diet. Virtual water trade distinctions

According to FAO (2003) a quarter of the world's lands are used for grazing and extensive pasture, and provides 30% of total beef production and 23% of mutton. As rangelands are decreasing as a result of conversion into arable land, land degradation etc. the opportunity for increasing the number of animals in these systems is small. Present trends point at increasing intensive large-scale industrial live stock production with a substantial rise in cereal based feeds. Nierenberg (2003) estimates that 43% of today's world beef production comes from feedlots. Industrial enterprises globally already stand for 74% of poultry production, 68% of egg production and 40% of pig meat (FAO 2003).

Van der Zaag stresses that the virtual water debate in relation to water demanding diets and its implications on global water resources is largely useless unless green virtual water and blue virtual water can be distinguished. From a global water use optimisation perspective we believe however that the major difference in livestock/meat production is whether it is based on non-arable rangeland grazing and agriculture biomass residues, or it is based upon feed production that competes for water resources with food production. If feed is grown on lands that can produce vegetarian food for humans, the consumptive water use on these lands, irrigated or rainfed, to produce feed calories could instead be used for vegetarian food calories. Since efficiency in converting feed protein into meat protein is low compared to a vegetarian diet, meat from these areas accordingly implies a more water intensive diet.

A theoretical case where un-committed blue water flows are used to irrigate a non-arable bush landscape to produce camel meat and the Botswana case with beef export from grazing lands with erratic rainfall, presented by van der Zaag, are thus both examples of meat production that does not impact the availability of global water resources for food production, but instead contribute efficiently to global food calorie production.

To optimise global water use for food production, water intensive meat diet versus vegetarian, it is accordingly not important to distinguish between green virtual water (rainfed) and blue virtual water (irrigated) produced meat but if human vegetarian food production from this consumptive water use would have been possible or not.

Smaller points

- Water demand management: The reference to water demand management is due to its focus on withdrawals although only part of that water is being really consumed, whereas the rest represents "imaginable losses" only, by returning to the system.

- Environmental flow - 30% only: this evidently allows quite far-reaching depletion but is already a fact in large areas of the world.

- Remaining degrees of freedom: Fig 5 shows the water withdrawal ratio against water crowding. While more irrigation would be equivalent to higher ratio, 70% can be seen

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as proxy for the maximum acceptable withdrawal level. This determines the remaining degree of freedom for expansion of irrigation in a certain basin. Since the withdrawal ratio includes also the return flow, it is however just a proxy.

- Trade of virtual water: a very good comment. What is referred to in Hong's study and by Mac Calla is inter-country trade since that is where there are trade data, while the points in Fig 5 represent basin data.

- Flow units: As flow unit we have chosen the most commonly one used in literature, km^3/yr. This unit is also easier for readers to internalise and relate to, compared to the scientifically more correct SI unit Gm^3/yr.

- Inaccuracy page 19: Shiklomanov (2000) estimated total consumptive water use, or total green water flow, from all blue water withdrawals in the world from different sectors and uses in 1995 to 2074 km^3/yr. The figure 2100 km^3/yr for total green water flow is therefore correct.

- Inaccuracy page 20: As pointed out by van der Zaag 2500 km^3/yr is total blue water withdrawals in agriculture. The correct figure for total consumptive water use from all blue water withdrawals should be 2100 km^3/yr. Consequently river depletion will rise to 2700 km^3/yr (instead of 3100 km^3/yr).

- Limpopo outlier in Figure 5: We much appreciate the increased accuracy of the data provided and have changed accordingly in the diagram.

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