5370 w **FINAL DRAFT**

INTEGRATING AGRICULTURAL WATER USE WITH THE GLOBAL WATER BUDGET

by Malin Falkenmark (1,2) and Johan Rockström (2,3)

1) Stockholm International Water Institute SIWI

2) Stockholm Resilience Center

3) Stockholm Environment Institute SEI

ABSTRACT

Water constitutes a key component in food production. While most attention in the past has been concentrated on blue/liquid water, this study represents a shift in thinking by incorporating also green water/naturally infiltrated soil water. The present consumptive water use in food production, estimated at some 7000 km3/yr, may be expected to increase till 2050 with altogether some 3000 km3/yr. The study analyses from where these amounts of water may come. It takes both a global and a country-level perspective, the latter based on a model study (LPJ model by the Potsdam Climate Institute), incorporating both climate change and population growth (slow fertility decline). The countries are analysed also in terms of water shortage, distinguishing between green water shortage and blue water shortage, trying to find out in what countries irrigation will not be a plausible way to meet green water deficiency. It shows that when both green and blue water resources are added, a number of countries in the North Africa, Middle East, W Asia, and S Asia regions will not be able to meet future food production needs on a self-sufficiency basis. In these countries the strategic choice for avoiding food insecurity will stand between import (virtual water), horizontal expansion to new land, or reduction of losses from food to plate. The study finally calls for attention to the additional water demand from the expanding biofuel sector, which will partly compete for the same land and water resources.

INTRODUCTION

Water is a key component in food production, both in terms of grain and of meat. The reason is the involvement of water in the photosynthesis process, both as a raw material besides carbon dioxide and in terms of nutrient-carrying substance rising through the plant from the roots to the leaf surfaces where it gets lost when stomata open to take in carbon dioxide from the air. Agriculture is often referred to as the largest water consuming activity, but this normally only refers to withdrawals (70 % of total withdrawals) and consumption of blue (liquid) water or runoff used for irrigation. In reality, water use for food production is more complex, including both blue water resources in irrigated agriculture and green water resources (soil moisture from infiltrated rainfall) in rainfed agriculture. The consumptive water use in agriculture is in the order of three and a half times larger than generally stated if including also green water use. On the other hand, agricultural water use as a whole is estimated to in the order of 7000 km3/yr, which can be compared to 110 000 km3/yr of precipitation over the world's land areas, i.e., only 6 % of the total freshwater resource.

In the past there has been a clear conceptual dichotomy between rainfed and irrigated agriculture. With the growing realization of the potential and large needs for upgrading of rainfed agriculture using supplementary irrigation for dryspell mitigation, that dichotomy starts to be at least partly outdated. On the one hand, irrigated crops have a basic supply of infiltrated rain, i.e. green water, on the other the dryspell mitigation involves supplementary irrigation, often using small-scale farm-level tanks as water sources. In semiarid smallholder farming there is today a tendency to harvest increasing amounts of local rain by conservation farming to increase infiltration and mulching to increase the water holding capacity of the soil.

The aim of this paper is to put food water requirements in a global perspective. Water availability is seen as the sum of blue and green water together, in an effort to demonstrate the importance of the green water resource for food production.The study will relate blue and green water availability in different countries to food water requirements by 2050. It will also try to estimate future options in terms of, on the one hand by expansion of croplands over pastures, grasslands or forests, on the other hand by virtual water trade. Taking a blue/green approach it will categorize countries by distinguishing between shortage and freedom of green and blue water , respectively *(* **Table 1)**. Green water is seen as short if the resource is below the per capita food requirements, and is otherwise characterized as freedom from shortage. Blue water shortage is beyond 1000 people per flow unit of 1 million cubic meters of blue water recharged per year, otherwise characterized as freedom from shortage.

Table 1. Water shortage categories.(Definition see Table 4)

/ Green Blue	**Green shortage**	**Green freedom**
Blue shortage	a	b
Blue freedom	c	d

METHOD

Shift in thinking

Attention is paid to the green water resource/soil moisture and the green water flow/evapotranspiration back to the atmosphere, involving consumptive water use in biomass production (**Figure 1**). The key water resource is theprecipitation, partitioned between the green water/soil moisture available to plants and the blue water/runoff resource available for societal withdrawal and control.

Figure 1. The green-blue approach to water resource, seeing precipitation as the freshwaterresource, which is partitioned in blue and green water flows, generating blue (groundwater, surface water) and green (soil moisture) resources. Source Falkenmark&Rockström 2006.

The green water flow is complex, in its combination of evaporation from wet surfaces (including interception losses) and the transpiration, directly involved in the plant production process. Where vegetation is thin, evaporation from wet soil between the plants often dominates over plant-producing transpiration, resulting in low water productivity in terms of ton biomass per cubic meter of water. In semiarid tropics, the rainfall amounts would allow much larger biomass outcome if the evaporation loss could be reduced by facilitating infiltration into the root zone.

Figure 2 illustrates the conceptualization. It shows the rainfall over a country and its partitioning between green water flow from different types of vegetation and blue water flow with its composition of irrigation water, environmental flow to be reserved for aquatic ecosystems, and the reserve that might to be allocated for other societal uses. The green water resource available for food production is in this paper seen as the green water in croplands and permanent pasture. This is the amount available to meet future food needs without expansion of cropland or food import.

Figure 2. Rainwater partitioning between green water in different lands and blue water resources for three countries. The first column shows the current situation, the three following ones the food water requirements 2015, 2030 and 2050. Source: SEI 2005

Water availability and food water requirement

The assessment of water shortages and the possibility for food self-sufficiency builds on the outcome of a recent study by Rockström et al (2008). The *water availability* analysis has been based on the process-based, pixel level LPJmL dynamic global vegetation and water balance model, extensively validated against biogeochemical and hydrological observations and including leaf phenology, crop yields, river discharge, soil moisture/green water, and green and blue water use (Gerten et al 2004). As already indicated, the green water availability analysis was made for current croplands and permanent grazing lands (Rockström et al., 2008).

The *food water requirements* were calculated as the crop evapotranspiration for production of the required amount of food, assuming current water productivity (crops produced per drop evapotranspired), and a food supply need of 3000 kcal/p/day out of which 20 % animal products. This corresponds to a water requirement of 1300 m3/p/yr. The 3000 kcal/p d is the food supply needed to avoid that certain population strata remain undernourished (Rockström et al 2007). 3000 is at the same time the level to which FAO in its report 2003, "World agriculture: Towards 2015/2030" (FAO 2003, Ed Bruinsma) estimated that food consumption would increase by 2030 as an average for developing countries. From a calory perspective, 3000 kcal/p d may be considered quite high, though. Some calculations have therefore been performed also for a considerably lower socalled "mini"-diet requiring only 600 m3/p d.

The water availability situation in 2050 was based on projections of future economic development and population rise from the World Bank, making the following assumptions: climate anomalies from the HadCM2 scenario (Mitchell et al 1995); the economy oriented SRES A2 carbon emissions trajectory (Nakicenovic and Swart 2000), and the related slow fertility transition projection (Bengtsson et al 2006). According to a recent study (Lundqvist et al 2007), food water requirements varies with income and has been shown to grow rapidly with increasing GDP, presumably due to diet change, up to some 10 000 dollars per capita and year. Beyond that income level, the water requirements tend to stabilize around an average of 5 m3/p d, or 1825 m3/p yr, **Figure 5**. The consumption depends a lot on the meat component, arriving at around 2000 m3/p yr for high-meat diet countries and around 1460 m3/p yr for countries with vegetarian diets. This suggests that the assumed level of water requirements of 1300 m3/p yr in this study is in fact a rather conservative value (3.6 m3/p d).

Figure 3. Water requirements for the food supply in countries at different levels of GDP (US dollars per capita in year 2000). Regression lines of maximum and minimum food supply. Source: Lundqvist et al 2007.

GLOBAL WATER BUDGET PERSPECTIVE

Crop production in the global water budget

The global water budget around 2000 is shown in **Figure 4** shows the estimate, based on a survey of literature quantifications of ET from different terrestrial ecosystems (Rockström et al 1999). It also shows blue water flow and blue water withdrawals, including the blue water partitioning into a consumptive use part and a return flow. It indicates that green water flow through croplands includes the blue water redirected into green water flow as the consumptive use fraction of irrigation water.

Figure 4. Global scale continental water balance and its estimated partitioning between green water resources in the soil and blue water resources in rivers and aquifers. Source: SIWI

As shown by Rockström et al (2008), the consumptive use of water in agriculture is dominated by green water also in many irrigated regions. In Europe, Africa and S America, crop production depends almost exclusively on green water, whereas the blue water component exceeds the green component only in parts of S Asia and N America. **Figure 5.**

*Figure 5***.** *Current blue and green water use in agriculture shown as percent of green water in agricultural consumptive water use for cropland and pasture. Source: Rockström et al 2008.*

Future food water requirements

The MVB projection (Lundqvist et al 2007) arrived at a global water requirement for the projected, income-related diets of altogether 10 500 km3/yr. In comparison, food water requirements for the 92 developing countries studied by Rockström et al (2007) would increase to altogether 9700 km3/yr. **Table 2** summarises a number of global projections of food water requirements as they are foreseen to grow up til 2050, with estimations of different ways to cover the additional water needed..

Table 2. Different estimates of additional food water requirements

consumptive use	assumption	total conumptive watr use km3/yr	additional needed km3/yr	options
Rockström et al 2007 - now	92 developing countries	4500		
2050		9700	+ 5200	*WPimprovem 2300 *irrig 700 *grazing 500 *rainw capture >360/2015 *expansion --> 450Mha
Lundqvist et al 2007 now	income-driven diets	7200		
2045		10500	+ 3300	*WPimprovem 2500 * 50%loss reduction
IWMI 2007 (CA) now	trade scenario	7130		
2050		9000	(+1800)	virtual transfer 1800
Rockström et al 2008 now	croplands only	8800		
2050	*SRES A2 global change *virtual deficiency related to B+G= 1300		+ 1700	virtual transfer up to 1700

Where is the extra water to support increasing food water requirements?

When food water requirements increase beyond the production capacity on present croplands and permanent pastures, the additional water may originate from four different sources:

- by cropland expansion to allocate green water from other land
- by rainwater harvesting on neighbouring land for use as supplementary irrigation
- by productivity increase through loss reduction:
- by import, i.e. allocation of virtual water from exporting countries.

Decoupling possibilities – how?

Thus, food water requirements can be moderated by limiting *water losses:* in irrigated agriculture, evaporation losses from canals and open water surfaces in the field (e.g. rice paddows); in rainfed agriculture water losses in terms of evaporation from open soil surfaces and of overland flow, by conservation tillage to increase infiltration and avoid flash floods. Green water flows from the farmer's fields can be better used by reducing the non-productive evaporation component (soil evaporation), i.e. what is referred to as improving "crop per drop" of evapotranspired water, or water productivity increase. The fraction of rainfall that is used for productive transpiration is generally less that 30 percent (Rockström 2003), but varies between agro-ecological systems and can be influenced by management. In sub-Saharan Africa for instance, this figure varies between 15 and 30 percent in the semi-arid zone, whereas in the temperate regions transpiration is around 45-55 percent of rainfall. By shifting non-productive evaporation to productive transpiration through crop and soil management, more food can be produced with the same amlount of green water. This improvement in green water productivity is an important opportunity for large water savings in agriculture on the field level, which allows more food to be produced without impacting on downstream water users.

But also *food losses* may be addressed to limit the current overproduction of food all the way through the food chain from field to fork: losses on the field (insects, plant diseases), during harvest, during transport, in the market, and in the households. Once that such losses could be avoided, water requirements for food production would be limited to the actual food intake. This would bring down the water needs considerably, especially if the water consuming meat content would be reduced. To reach all these "from field to fork"-efficiency increases will however be a complex process where many different actors and activities would have to be involved (SIWI 2008).

COUNTRY LEVEL PERSPECTIVE

Current situation

Water shortage aspects: The study by Rockström et al (2008) revealed considerable regional differences. **Figure 6** shows the relation between blue and blue+green water availability for a number of countries in 2000AD. Total available green and blue water availability (vertical axis) is compared with available blue water only (horizontal axis). Solid vertical line indicates the limit for chronic blue water shortage; dotted vertical line the limit for blue water shortage; solid horizontal line indicates the limit combined water shortage; diagonal solid line zero green water availability; and diagonal dotted line green water availability 600 m^3 cap^{-1} $yr^{-1.}$ The diagram has been divided into different water shortage domains, see **Table 3**.

Figure 6. Water shortage domains 2000.˙ Red area = A; green area = B_1; yellow area = B_2; blue area = C; white area = D (see Table 3). Source: Rockström et al (2008)

Table 3. Four water shortage domains. Blue+green(B+G) is overall water availability), Blue (B) is blue water availability only. Source: Rockström et al 2008.

Water shortage domains 2000 AD

Area in Fig 6	*Characteristics and some cases*
A	* B+G less than 1300 m3/p yr * B less than 1000 m3/p yr (water crowding of 1000 p/flow unit of 1 million m3/yr) * example: Israel, Iran, Pakistan, Pakistan
B	* B+G more than 1300 m3/p yr * B1 less than 1000 m3/p yr (more than 1000 p/Mm3/yr) * example: Morocco, Algeria, Uganda, Eritrea * B2 less than 1700 m3/p yr yr (more than 600 p/Mm3/yr) example: Iraq, India, China, Ethiopia
C	* B+G more than 1300 m3/p yr * G less than 1300 m3/p yr * example: Egypt, Bangladesh
D	* others * example: Sri Lanka, S Africa, Tanzania, Mali

What is particularly interesting in that diagram is to note that many African countries that are conventionally seen as suffering from economic water scarcity and often suffer from undernutrition and poverty turn out to be quite rich in green water when estimated as evapotranspiration from croplands and permanent pastures. Examples are Namibia, Boptswana, Chad, Zambia, Mozambique and Sudan, which all have more than 7000 m3/p yr of green water availability.

Green water reserve and vapour shift option: As_ earlier indicated, reduction of water losses would allow an increased production within the same evapotranspiration. Analysis of the productive fraction of the green water consumption has shown that large green water losses in terms of unproductive flow are frequent, in other words that transpiration is far below the total ET from croplands. This means that there is a potential for vapour shift by various measures to increase water productivity, increasing the crop yields within the same overall consumptive water use/green water flow.

Figure 7 shows the position of a number of countries relative to the “mini”-diet line 600- m3/p yr of green availability. This represents a net food water requirement where all “field-to-fork”-losses have been controlled and meat content in diet reduced to below 10 %. With this lower line all field-to-fork losses are assumed to be avoided. Inside that line, we find countries where green water availability is not enough for a country to be self sufficient from rainfed agriculture, even at the “mini”-level of food intake. Countries normally portrayed as subject to water shortage, where this analysis indicates significant green water potentials to produce more food (far away from the 600-line) include Kenya, Ethiopia, Mali, Pakistan, India, Bangladesh.

Figure 7. Transpiration versus available green water in 2000 AD. Ratio between green water use and availability i.e. transpiration efficiency (vertical axis) compared with green water availability (horizontal axis). The solid line indicates a transpiration efficiency corresponding to producing a”mini”-diet requiring 600 m^3 cap^{-1} yr^{-1} water. Source: Rockström et al (2008)

The diagram shows that many countries for which the green water availability is below the 600-line are in fact loosing large quantities of green water by evaporation losses, i.e. show a fraction of productive green water use below 0.8. This suggests a *remaining potential* to increase yields by increasing water productivity. Largest potential is available in for instance Bangladesh, Pakistan and India, and to a certain degree also in China, Iran, Iraq - even Jordan and Israel.

Global projections 2050 and predicament changes

When discussing water availability as the sum of blue and green water together, we have aimed at demonstrating the importance of the green water resource for food production. **Figure 8** shows green/blue water availability by 2050, assessed by modeling future water availability and demand with due attention to climate change and population growth. A considerable group of countries will fall below the 1300 m3/p yr level, i.e have genuine water shortage even when *adding green and blue water availability*. This group encompasses countries in N Africa, W Asia and S Asia. Close to that threshold are China, Mali and Ethiopia having less than 1500 m3/p yr

Figure 8. Country-level LPJmL-simulated per capita green plus blue water for 2050, assuming both climate and demographic change. Source: Rockström et al (2008)

When it comes to practise, however, the question of course remains to what degree the *blue water is really accessible* for irrigation in cases where the green water resource is deficient for the food water requirements. At this point one has to look at the blue water shortage separately – if it is too high, irrigation is not a realistic alternative, especially in view of the need to conserve a certain amount of river discharge for the aquatic ecosystems.

In **Figure 9** we try to consider this *type of predicament* for some countries, showing agricultural water requirements in relation to green water availability (vertical axis) compared with level of blue water crowding (persons per flow unit, horizontal axis). The vertical solid line indicates where chronic water shortage starts (SIWI, 2007), while the horizontal solid line represents total green water availability on current croplands and permanent pasture, i.e. without need for horizontal cropland expansion. The arrows link the situations in 2000 and 2050 and their position in the diagram show

a) to what degree green water on current croplands and permanent pastures can meet food water requirement (below 100 % in the graph)
b) when requirements are beyond 100 % green availability, whether the level of blue water shortage is too high (beyond 1000 p/flow unit) to realistically allow irrigation to complement deficient green water availability.

Thus, in the pink field, irrigation is not very realistic but food security by 2050 will be requiring additional water from other sources: radically increased water productivity (more crops per drop of

ET), virtual water import (trade) or allocating green water from other arable land areas, i.e. expansion of croplands into grasslands and forests (cf Figure 2) .

Figure 9. Long-term water predicament when trying to meet food water requirements now (beginning of arrow) and in 2050 (end of arrow. Green and blue water availability data from LPJmL, green water requirement data from Rockström et al., (2007).

The predicament can also be categorized in terms of the earlier mentioned water shortage categories a, b, c and d, see **Table 1 and 4.** It shows that many African countries are quite well-off in terms of both blue water and green water availability.

Figure 10 summarises the implications for global food supply by 2050 in terms of the size of populations under different kinds of dilemmas. It suggests a major rise in populations in countries dependent on food import.

Table 4. Water shortage combinations foreseen by 2050

GREEN ---------- ***BLUE***	**Green shortage <1300m3/p yr**	**Green freedom >1300m3/p yr**
Blue shortage <1000m3/p yr	a **Iran,Pak,Jordan Eg,Eth,India, China**	b **Kyrg, Czeckosl, Les, S Afr**
Blue freedom >1000m3/p yr	c **Jap,Bangl,N+SKor, Nga. To,**	d **Zimb,Ghana, Ang,Botsw, Chad,Ke,Mali,Namib, Sud, Ta,Za,Zimb**

Figure 10. Percentual distribution of world population by 2050 under different water shortage predicaments
Legend: "standard diet" = 1300 m3/p yr; "mini"-diet = 600 m3/p yr

Virtual water trade implications

Countries with less than 1300 m3/p yr green availability and incapable of irrigation due to chronic blue water shortage, may have to import food from more water abundant regions. Current food trade has been estimated to involve an amount of virtual water transferred of 1140 km3/yr (Oki&Kanae 2003), and Yang (2003) showed that food import tends to increase with increasing blue water shortage below 1500 m3/p yr. The order of magnitude of future food import is very difficult to estimate, but food water deficiencies may offer some indications. If we first consider group A in Table 4, it hosts a 53 % of the projected 2050 world population.. If those countries would have to import all their food, that would correspond to a virtual water transfer of some 7500 km3/yr. Since it is however only the water deficiency that has to be compensated, the overall water deficiency offers a low estimate: some 1700 km3/yr in the poor countries with rapid population growth. Since the present food trade is primarily between the industrialised countries, this suggests more than a doubling of food trade till 2050. For comparison, IWMI in the Comprehensive Assessment of Water use in agriculture foresees a total food trade corresponding to 1800 km3/yr, cf Table 2. Countries with particularly large virtual import needs (more than 100 km3/yr) include India, Iran, and Pakistan.

Besides food trade, food water deficiencies can be met also by *horizontal expansion of croplands* and permament pasture. The recent study by Rockström et al (2007) estimated, based on a realistic assumption of increases in water productivity and irrigation expansion, that a minimum of 900 km3/yr of additional consumptive use of water in agriculture would be needed, which either would have to originate from expansion of agricultural area or covered through imports. The rate of cropland expansion implied by this growing need for food production, would imply a continuation of the present rate of cropland expansion.

DISCUSSION AND CONCLUSIONS

Method

The aim of the addition of adding blue and green water availability (B+G) in the discussion has been to get out of the past dichotomy of irrigated versus rainfed agriculture, especially since most of the water consumed even in irrigated agriculture is generally green water. It is the combination of these two forms of water that is relevant for food production

The analysis in this paper can be seen as fairly robust by defining green water resource as only the ET-flow on croplands and permanent grazing lands. Thereby,we in other words restrict the resource to water that is already under agriculture. In the analysis, more green water can be “grabbed” from other terrestrial ecosystems (forests, grasslands etc, cf Fig. 2) by horizontal expansion.

The blue water generation is calculated as the residual in the water balance. No attention is however in this version of the model paid to the blue water evaporation losses during the flow through the landscape. This means that in certain arid regions the blue water flow is overestimated as compared to runoff models, calibrated against gauges streamflow. The model does in other words not distinguish between blue water generation and blue water availability, which has particularly large effect for the Nile because of the huge year-round evaporation from the Sudd wetland area and from the surface of Lake Nasser (Gerten et al 2004).

With current water productivity, FAO’s projected average food consumption by 2030 in developing countries of 3000 kal/p d – fairly high as seen from a dietary perspective - gives a food water requirement of 1300 m3/p yr if assuming 20 percent animalm protein. When compared to present dietary water use (cf Fig. 3), this level however turns out to be fairly moderate by corresponding to average food water requirements at an income level of 10000 dollars per person and year.

Water for food

In spite of this conservative approach, on the one hand limiting the green water resource, and on the other applying FAO’s fairly high calory level, this green-blue approach shows that most agriculture is currently supported by green water. The blue water contribution through irrigation is in fact fairly limited. Many countries show large green water losses in terms of unproductive evaporation (Figure 7) and could increase their food production within the same consumptive use.

Massive water deficiencies may be expected during next few decades and involve strategic choice – after water productivity increase - between cropland expansion and food import (Figure 9). Massive food trade increase may be expected if food production on the 3000 kcal/p d –level is taken as a goal, corresponding to a virtual water import of some 1700 km3/yr as a minimum (for the case that all blue water can be used and consumed). Some blue water short countries will have a green water surplus to benefit from (Table 4). Countries with altogether 3.9 bln inhabitants will develop severe food water deficiency (B+G < 1300 m3/p yr) till 2050.

Large field-to-fork food losses currently exist, however. If such losses can be avoided and better food distribution to poor strata can be secured without overproduction a production on only the “mini”-diet would bring down virtual water deficiency to of the order of 250 km3/yr only.

Strategic choices

In regions where water shortages do not allow the production of enough food for the population (water requirements beyond 100 percent of the green water resource), there are a set of options for achieving food security:

a) *irrigation* where blue water resource permits, i.e. chronic water shortage does not hinder;

b) *horizontal expansion* of cropfields by “grabbing” green water from other land (cf Fig.2);

c) in semiarid tropics socalled *vapour shift*, benefiting from the fact that evaporation losses decrease when vegetation cover gets denser, i.e evaporation from open soil areas decreases. Non-productive evaporation can in other words be turned into productive transpiration

d) reduction of the dietary requirements by better distribution of food in society. A healthy diet can be restricted to the order of some 2400 kcal/p d, i.e a reduction of 20 percent provided that *field-to-fork losses* of food can be diminished (SIWI 2008).

e*) food import*, benefiting from green water resource in the exporting region.

The primary options will look different for different water shortage situations as indicated in **Table 5** which also shows the percentual size of populations in the most critical regions a and c which host considerable populations. Many African countries however belong to categories b and d and can make much better use of their green water resources.

Final remarks

Finally, the role of biomass in meeting energy demand has to be brought into the picture to get a proper hold on future water requirements for biomass production. Although modest at present, the contribution of biofuels to energy supply is expected to grow quickly (Berndes in Lundqvist et al 2007). This means that the competition for water by 2050, sketched in this paper will have to compete also with other crops: both for bioenergy production and for non-food crops like cotton, which is expected to more than double by 2050.

Table 5. Some policy implications

GREEN ------------- ***BLUE***	**Green shortage** <1300m3/pyr	**Green freedom** >1300m3/pyr
Blue shortage <1000m3/pyr	a **53 % of world pop** * horisontal expansion * food import * radical water productivity increase	b * upgrading rainfed agric/ chronic blue water shortage
Blue freedom >1000m3/pyr	c **21% of world pop** * irrigation	d * upgrading rainfed agric *irrigation

REFERENCES

Bengtsson, M., Y. Shen and T. Oki (2006), A SRES-based gridded global population dataset for 1990-2100. *Population & Environment*, 28, 113–131.

Falkenmark, M. and J. Rockström (2004), *Balancing Water for Humans and Nature. The New Approach in Ecohydrology*. Earthscan, London, 247 pp.

Falkenmark, M., and Rockström, J., 2006. The new Green and Blue water paradigm: Breaking new ground for water resource planning and management. *J. Water Resource Planning and Manage.* 123 (3): 129 - 132

FAO (2003*) World agriculture: towards 2015/2030* An FAO Perspective, Edited by Jelle Bruinsma, Earthscan, London

Gerten, D., S. Schaphoff, U. Haberlandt, W. Lucht, and S. Sitch (2004), Terrestrial vegetation and water balance: hydrological evaluation of a dynamic global vegetation model. *Journal of Hydrology*, 286, 249–270.

Mitchell, J. F. B., T. C. Jones, J. M. Gregory, and S. F. B. Teff (1995), Climate response to increasing levels of greenhouse gases and sulphate aerosols. *Nature*, 376, 501−504.

Lundqvist, J., J. Barron, G. Berndes, A. Berntell, M. Falkenmark, L. Karlberg and J. Rockström (2007), Water pressure and increases in food and bioenergy demand - implications of economic growth and options for decoupling. In: *Scenarios on economic growth and resource demand.* Background report to the Swedish Environmental Agency Council memorandum 2007:1. pp 55-151.

Nakicenovic, N., and R. Swart (Eds.) (2000), *Special report on emission scenarios.* Cambridge University Press, Cambridge, 599 pp.

Oki, T.& Kanae, S. 2003. Virtual water trade to Japan and in the world. *Drainage basin security – Balalncing Production, Trade and Water Use*. Abstract volume pp341-344. Stockholm Water Symposium 2003. Stockholm International Water Institute

Rockström, J., Gordon, L., Folke, C., Falkenmark, M. & Engwall, M. (1999) Conservation Ecology 3(2): 5, http://www.consecol.org/vol3/iss2/art5

Rockström, J., M. Lannerstad, and M. Falkenmark (2007), Assessing the water challenge of a new green revolution in developing countries. *PNAS*, 104, 6253–6260.

Rockström, J.,, Falkenmark, M., Karlberg, L., Hoff, H., Rost, S.& Gerten, D. 2008. Future water availability for global food production: the potential of green water for increasing resilience to global change Under review

SEI (2005) Research Report. Stockholm Environment Institute, Stockholm, Sweden. p 114 http://www.sei.se/mdg.htm

SIWI 2008. *Saving water: From field to fork. Curbing losses and wastage in the food chain*. Draft for CSD, May 2008. Stockholm International Water Institute

Yang, H., Reichert, P., Abbaspour, K.C.&Zehnder, A.J. 2003. A water resources threshold and its implications for food security. In: *Virtual water trade, Proceedings of the international expert meeting on virtual water trade*. Ed.A.Y.Hoekstra. Delft

Figure Legends

Figure 1 The green-blue approach to water resource, seeing precipitation as the freshwaterresource, which is partitioned in blue and green water flows, generating blue (groundwater, surface water) and green (soil moisture) resources. Source Falkenmark&Rockström 2006.

Figure 2. . Rainwater partitioning between green water in different lands and blue water resources for three countries. The first column shows the current situation, the three following ones the food water requirements 2015, 2030 and 2050. Source: SEI 2005

Figure 3. Water requirements for the food supply in countries at different levels of GDP (US dollars per capita in year 2000). Regression lines of maximum and minimum food supply. Source: MVB 2007.

Figure 4. Global scale continental water balance and its estimated partitioning between green water resources in the soil and blue water resources in rivers and aquifers. Source: SIWI

Figure 5. Current blue and green water use in agriculture shown as percent of green water in agricultural consumptive water use for cropland and pasture. Source: Rockström et al 2008

Figure 6. Water shortage domains 2000.˙ Red area = A; green area = B_1; yellow area = B_2; blue area = C; white area = D (see Table 3). Source: Rockström et al (2008)

Figure 7. . Transpiration versus available green water in 2000 AD. Ratio between green water use and availability i.e. transpiration efficiency (vertical axis) compared with green water availability (horizontal axis). The solid line indicates a transpiration efficiency corresponding to producing a”mini”-diet requiring 600 m^3 cap^{-1} yr^{-1} water. Source: Rockström et al (2008)

Figure 8. Country-level LPJmL-simulated per capita green plus blue water for 2050, assuming both climate and demographic change. Source: Rockström et al (2008)

Figure 9. Long-term water predicament when trying to meet food water requirements now (beginning of arrow) and in 2050 (end of arrow. Green and blue water availability data from LPJmL, green water requirement data from Rockström et al., (2007).

Figure 10. . Percentual distribution of world population by 2050 under different water shortage predicaments

Legend: “standard diet” = 1300 m3/p yr; “mini”-diet = 600 m3/p yr