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Meeting water requirements of an expanding world population

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SUMMARY

Water availability in the root zone ('green water') is a critical component of plant production, but is often deficient in many Third World regions. When deficient, runoff water ('blue water') can be added. Focusing on ten physiographic regions in Africa and Asia, characterized by mainly or partly dry climates and rapid population growth, this study analyses whether in a 30-years' perspective enough blue water could be provided to allow food self-sufficiency. It is assumed that for food self-sufficiency some 900 cubic metres of water per person per year has to be provided. In judging the realism it is assumed that a maximum 25 % increase in water mobilization rate would be manageable in a 30-year period. The study suggests that by 2025, water scarcity will make regions populated by some 55 % of the world's population dependent on food imports. For water-wasting regions in Central Asia, water saving might, however, free the water needed. The paper closes by proposing some urgent measures.

1. INTRODUCTION

The basic issue for discussion at this meeting is the ability of soil and water resources to provide for the future population of the world. The problems are of a scientific and a managerial nature. The focus of this contribution is fresh water, and the interaction in crop production between soil moisture (referred to here as 'green water'), and water in aquifers and water courses (here called 'blue water'). Given that water is one of the two key raw materials in photosynthesis, water availability in the root zone is a critical component of biomass production. The process is highly water-consuming due to large water losses from foliage when stomata open to take in carbon dioxide.

Different types of plants respond differently to deficiencies in root zone water. Such deficiencies tend to reduce the resulting yield response. A green water deficiency can be remedied by conventional irrigation or other ways of drought-proofing, *inter alia* by allowing local water surplus to infiltrate the root zone. This paper focuses on the ability of blue water resources to contribute to the production of a crop large enough to feed the future population in the semi-arid regions. These regions are at present responsible for a major part of the overall growth of the world population by some 86 million people each year. The overall growth is equivalent to feeding an additional India each new decade. What are the critical constraints involved? The time-scale taken will be 30 years, i.e. up to 2025—a point in time no earlier than 1965. Attention will be paid both to potential water limits and to societal realities.

The conventional approach taken to agriculture in dry climate regions has often been to move people to the water, e.g. the ancient river civilizations (Hillel 1991), or to move the water to the people, e.g. during the settlement and economic development of the Western USA (Reisner 1993). Today, many low-income, food-deficient countries with rapid population growth are situated in the dry regions of Africa and Asia. In response to a rising awareness of the massive scale of the food security problem in these regions, often with a high evaporative demand, a third option is being suggested for regions which cannot be self-sufficient in crop production: to import so-called virtual water by importing food grown in less drought-prone regions. As will be shown here, this is a highly probable, perhaps unavoidable development, in view of the considerable problems in trying to produce the amount of food needed on a national level.

Widespread green water scarcity is, for climatic reasons, typical for large parts of these regions (Falkenmark & Rockström 1993). This scarcity has to be compensated for by adequate ways of avoiding crop failures due to erratic rainfall, intervening drought years, and other calamities. The analysis focuses on how much blue water would be needed to secure food self-sufficiency from crop production, and how much out of the amount needed can realistically be made accessible within a 30-year period. Since almost 80 % of the population in 2025 will be living in the dry regions in Africa and Asia, the study will concentrate on these regions.

2. METHOD

(*a*) *Database and regionalization*

The database relied upon is the very extensive global water resources assessment that has recently been compiled within the International Hydrological Programme by Russian hydrologists under the leadership

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of Professor Shiklomanov at the State Hydrological Institute in St Petersburg (Shiklomanov 1996). These studies have been summarized in the framework of the Comprehensive Freshwater Resources Assessment (CFWA), initiated by the UN Commission on Sustainable Development. The outcome of that study (ECOSOC 1997) was presented to the UN General Assembly at the fifth anniversary of the Rio UNCED Conference in June 1997.

The scale on which the present study is being carried out is controlled by the scale on which worldwide and consistent data are available. Since many countries share similar characteristics and concerns, the regionalization developed in the Russian study will be relied upon to make an overview possible and to bring out fundamental differences between different developing regions of the world. The physiographic regionalization is based on hydroclimate and topography, dividing the world into 26 different regions (Appendix 1).

(*b*) *Water requirements to compensate green water deficiency*

Since the water requirements of crop production are being analysed by other contributors to the Discussion Meeting, I will focus on the possibilities of meeting the needs for additional blue water. Attention will be paid also to urban and industrial water needs.

Per capita water needs will be expressed as multiples of an assumed long-term household need at a decent and realistic quality of life in developing countries, assumed to be 100 litres of water per person per day ($1\ p^{-1}\ d^{-1}$) (Falkenmark 1989). This unit is denoted by the symbol H. A water need of 1 H is, in other words, equivalent to $36\ m^3\ p^{-1}\ yr^{-1}$.

Since water needs for food production will vary with a number of factors, both crop-related factors such as crop selection, cultivation patterns, and agricultural factors such as irrigation management, land management and cultivation practices the approach taken is schematic also in this regard. An earlier study (Falkenmark 1993), based on an FAO study by Higgins *et al.* (1988), concluded that the amount of water needed for self-sufficient food production in a semi-arid climate corresponds to some 20 H.

The FAO, in the discussions leading up to the CFWA and the World Food Summit (Klohn 1996), made the following approximations: (i) a good nutrition level implies $2700\ kcal\ p^{-1}\ d^{-1}$ with 2300 kcal plant-based and 400 kcal animal-based. Production of the former consumes $1\ m^3$ per 1000 kcal, the latter $5\ m^3$ per 1000 kcal: altogether, this amounts to $4.3\ m^3\ p^{-1}\ d^{-1}$ or $1570\ m^3\ p^{-1}\ yr^{-1}$. In an arid climate, all of this would have to be provided by blue water. In a humid climate, all may be provided by green water (soil moisture). In a semi-arid climate, we may assume 50% green water, 50% blue water, leading to $800\ m^3\ p^{-1}\ yr^{-1}$ for food self-sufficiency, or 22 H.

An alternative calculation would be the following: for an acceptable, mainly plant-based diet, $250\ kg\ p^{-1}\ yr^{-1}$ is needed (cf. annual per capita grain use in 1990: India $200\ kg\ p^{-1}$, China $300\ kg\ p^{-1}$ (Brown & Kane 1994)). In the dry climate tropics and subtropics, the typical evaporative demand amounts to 1500–2000 mm yr^{-1} or 125–170 mm per month. For a four-month crop, this adds up to 500–680 mm or, with a crop water satisfaction factor of 0.8, 400–540 mm per crop. Where the yields are only 1 ton ha^{-1}, four persons could be fed per hectare, whereas for 2 ton ha^{-1}, eight persons could be fed. In the former case, taking the lower water demand, this corresponds to $1000\ m^3\ p^{-1}\ yr^{-1}$ ($4000\ m^3$ per four persons) or 28 H, in the latter to $500\ m^3\ p^{-1}\ yr^{-1}$ ($4000\ m^3$ per eight persons) or 14 H.

In addition to the water needed for plant production, the water needs of households are assumed to be 1 H, plus the water needed for industry. Industry may need anything between, say, 10 H (Swedish industry, which is fairly water-efficient, uses some 12 H) down to 1–2 H when water is really scarce and industry is highly water-efficient. Given these estimates, the gross need of complementary blue water in semi-arid regions accepted for this study is 25 H. This is assumed to be the amount of blue water needed in a dry climate, low latitude country that goes for self-sufficient food production.

For comparison, it has been shown earlier that the median water requirements as seen on a country level were, by 1990, around what corresponds to 15 H (Margat 1995). The calculations here will be based on an overall (blue) water requirement level of 25 H. At present, water uses of some 40 H, and even more, are widespread in countries with a high degree of irrigated agriculture.

3. ANALYSIS

(*a*) *Characterization*

First, the water management situation in the 26 different regions will be characterized, expressed by the following three parameters:

(i) *Population pressure*

Population pressure on the total amount of available (blue) water (demographic water scarcity), expressed as people per flow unit of one million cubic metres of water per year. This parameter expresses on the one hand the level of dispute proneness in a country or region, since the finite water availability has to be put to a set of parallel uses, generating disputes between sectors and users, urban and rural water uses, upstream and downstream water uses, and between water-dependent and water-impacting activities. On the other hand, it also expresses the number of people polluting each flow unit of water, thereby providing an indication also of the pollution load. Five different intervals will be introduced: flow unit below 100 persons, 100–600, 600–1000, 1000–2000, and beyond 2000, respectively (Falkenmark 1993).

(ii) *Mobilization level*

Mobilization level, or total water withdrawal, as a percentage of the overall availability (technical water scarcity), giving an indication of the level of management difficulties: the European experience shows

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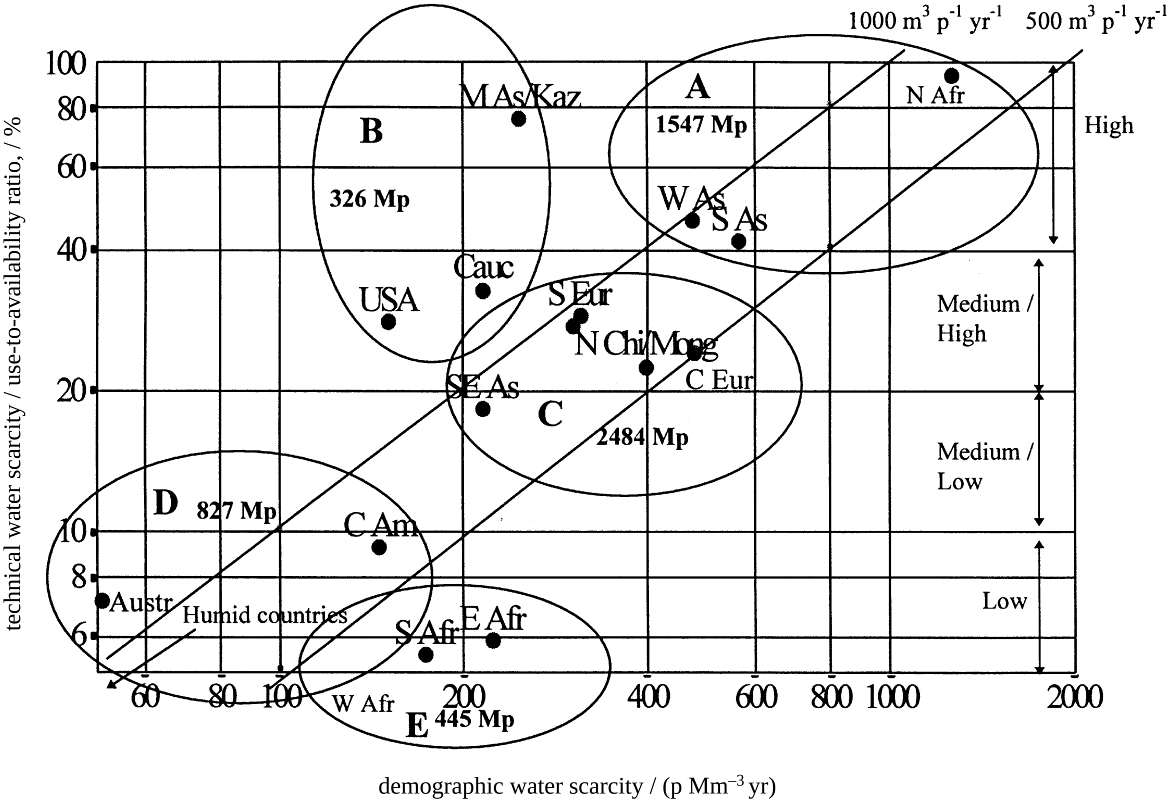

Figure 1. Global differences between regions with different characteristics in terms of demographic and demand-related water scarcity. Five different clusters are shown including the total population 1994 in each.

that above 20 %, management costs start to be large in relation to the national economy (Szesztay 1970). In low latitude countries with high evaporative demands, some 50 % is seen as the limit for what is realistically attainable, in view of the evaporation losses from surface water resource reservoirs. The categorization used in this study is the one used in the CFWA (ECOSOC 1997): below 10 % (low water stress), 10–20 % (medium to low water stress), 20–40 % (medium to high water stress), 40–100 % (high water stress), and above 100 % (basically meaning over-exploited aquifers and/or desalination).

(iii) *Per capita water use level*

Per capita water use level is expressed on the H-scale. Levels far above the 30 H level indicate wasteful water use through low water use efficiency in irrigated agriculture. This is seen as indicating a margin for demand management (freeing water for other uses or 'doing more out of less').

Figure 1 gives an overview of the world situation in 1995. The water management problems are shown in a log-log diagram of the population pressure per flow unit of water on the horizontal scale, and mobilization level (% of the total availability) on the vertical scale. Diagonal lines indicate the 1000 m^3 p^{-1} yr^{-1} (28 H) and the 500 m^3 p^{-1} yr^{-1} (14 H) levels, respectively.

(*b*) *Assessed situation by 2025*

The water management predicament by 2025 will be calculated in two steps. Attention will first be paid to the population growth only, assuming unchanged per capita water use levels. The emerging population pressure per flow unit of water and the mobilization level needed will be calculated. The results could be thought of as a diagonal arrow in the diagram parallel to the 1995 use level lines, indicating how the water management problems would sharpen just as a consequence of the expanding number of individuals needing to be supplied—even assuming no change in terms of socio-economic improvements or agricultural production.

Next, the situation by 2025 will be calculated assuming that 25 H will be needed in semi-arid regions to permit food self-sufficiency. The resulting change in mobilization level will be indicated by a vertical arrow in the diagram, showing how much more water will have to be mobilized to enable self-sufficient food production, and to protect from crop failures due to erratic rainfall and droughts.

4. RESULTS

(*a*) *Overview*

The predicament of the 26 regions can be organized in a grid-net showing the mobilization levels and the population pressure levels presented above (table 1), which shows that the regions tend to concentrate in eight of the 24 cells. A closer analysis has been limited to the ten physiographic regions in Africa and Asia where mainly or partly dry climate, high evaporative demand, and rapid population growth coincide. The resulting data are given in table 2.

Figure 2 shows the predicted changes during the period 1995–2025 for these ten dry climate regions.

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Table 1. *1995 characteristics of the 26 world regions. Data from Shiklomanov (1995)*

	population pressure on water availability p/flow unit					
withdrawal (%)	< 100	100–200	200–600	600–1000	1000–2000	> 2000
< 10	N. South America W. South America E. South America C. South America Siberia/Far East Oceania N. Europe N/FSU* Canada/ Alaska C. Africa Australia	S. Africa W. Africa C. America	E. Africa			
10–20			S. E. Asia			
20–40		USA	N. China/ Mongolia Caucasus S/FSU* C. Europe S. Europe			
40–100			S. Asia W. Asia M. Asia/ Kazakhstan		N. Africa	

* FSU = Former Soviet Union.

Table 2. *Demographic and technical water scarcity in ten dry climate regions in Africa and Asia*

region	water availability (km^3 yr^{-1})	population pressure 1995 (p mln m^{-3} yr)	withdrawal ratio 1995 (% available water)	projected population pressure for 2025 (p mln m^{-3} yr)
N. Africa	111	1261	94.6	2477
S. Africa	442	173	5.5	369
E. Africa	762	221	5.9	633
W. Africa	1103	181	2.1	473
N. China/Mongolia	1029	397	22.7	603
S. Asia	2138	565	41.9	947
W. Asia	490	474	46.3	902
S. E. Asia	6706	215	18.4	275
M. Asia/Kazakhstan	204	246	76.5	173
Caucasus	74	214	33.0	204

The growing dependence on mobilizing a larger share of the water availability is indicated by (i) the change in demographic water scarcity due to a growing population, and (ii) the increased mobilization needed to secure 25 H for food self-sufficiency. Since some regions were, by 1995, already using more than that amount, due to highly wasteful irrigation projects (M. Asia/Kazakhstan and the Caucasus), the second step may sometimes, as indicated earlier, imply reduced water requirements, i.e. freeing the water needed by demand management. It is assumed that the societies in Africa and Asia will scarcely be able to achieve more than a 25% mobilization increase within a 30-year period. The set of classification criteria selected for characterization of the manageability of the emerging situation is presented in table 3. Final results are presented in table 4.

Analysing from the water mobilization steps that have to be taken in order to supply the water needed for, first, the growing population on the present per capita level, and then for securing food self-sufficiency, the table shows that (i) the increases might be manageable in S. E. Asia—altogether 1.8 billion people; (ii) the situation might be manageable by water saving in M. Asia/Kazakhstan and the Caucasus—altogether 0.05 billion people; (iii) the water requirements are rising too quickly through food self-sufficiency demands in S. Africa, W. Africa, E. Africa and N. China for society to be able to cope—altogether 1.8 billion people; and (iv) already the population growth rate makes it unrealistic to supply water on the same per capita level as is supplied at present; food self-sufficiency needs make it even more unrealistic in N. Africa, S. Asia, and W. Asia—altogether 2.8 billion people. This is the most critical belt.

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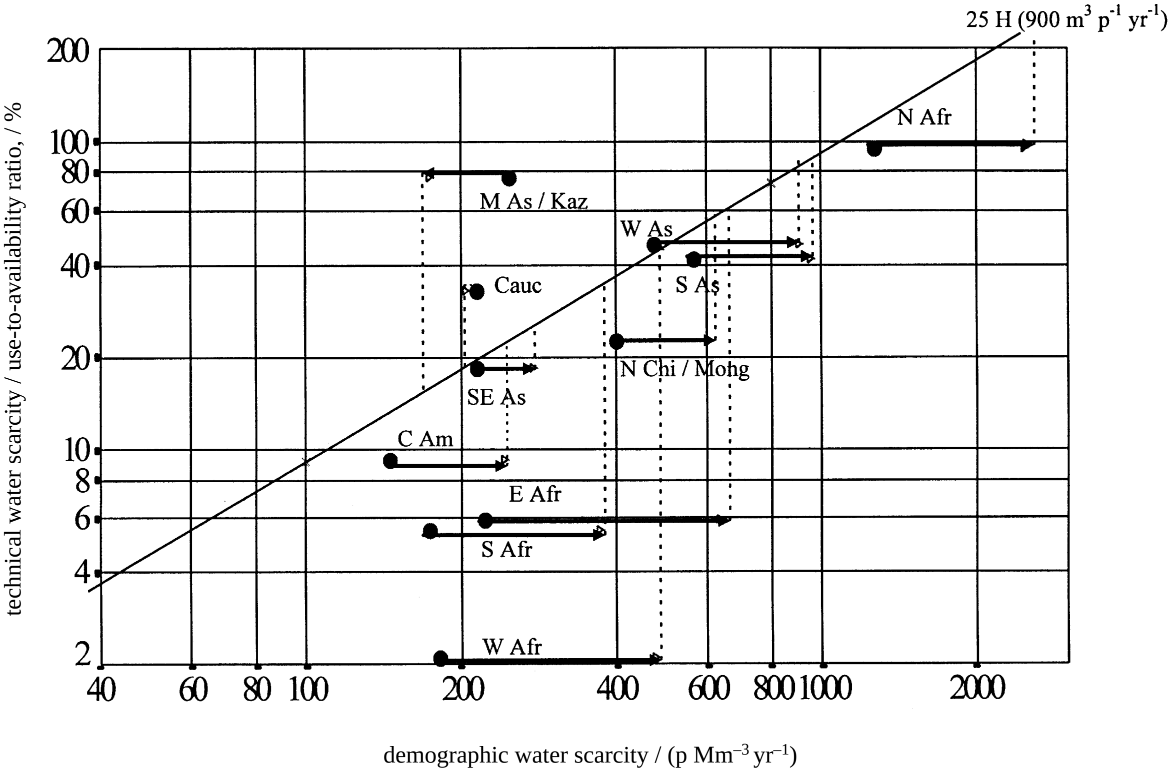

Figure 2. Possibility of food self-sufficiency. The diagram shows the resulting water demand (as a percentage of total water availablity, vertical axis) when 25 H or 900 m^3 p^{-1} yr^{-1} (diagonal line) is needed to support a certain population. The horizontal axis shows the demographic water scarcity (people per one million cubic metre of annually recharged fresh water).

Table 3. *Manageability problems—classification structure*

	criterion	description
steps	population and food steps together < 25 %	mobilization needs manageable
	population step < 25 %. Population and food steps together > 25 %	population growth manageable—food self-reliance involves too rapid mobilization needs
	population step > 25 %	manageable by water saving
	present water use > 25 %	manageable by water saving
levels	mobilization level < 20 %	mobilization manageable
	mobilization level 20–40 %	mobilization manageable, but costly
	mobilization level 40–100 %	mobilization complicated—food self-reliance not realistic
	mobilization level > 100 %	food self-reliance unrealistic

Table 4. *Final overview and size of population concerned by 2025*

steps	> 100 %	level at 2025 (40–100 %)	20–40 %	< 20 %
already using > 25 H		M. Asia/Kazakhstan (0.04 billion)	Caucasus (0.02 billion)	
rate of population and food growth both manageable (together < 25 %)			S. E. Asia (1.8 billion)	
food requirements growing too rapidly (joint demand > 25 %)		E. Africa N. China W. Africa (1.6 billion)	S. Africa (0.16 billion)	
population growth unmanageable (> 25 %)	N. Africa (0.28 billion)	W. Asia S. Asia (2.5 billion)		

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5. DISCUSSION AND CONCLUSION

The analysis applies to mainly or partly dry climate regions in Africa and Asia only. These are, however, the regions with the most rapid population growth, and will be hosts to more than 75% of the world's population by 2025. It has been assumed in this study that the water requirements will grow for two reasons: (i) to supply the additional population at the same standard as provided in the region today, and (ii) to allow the water supply for the whole population to increase to 25 H, in order to enable self-sufficient crop production based on fairly water-efficient traditional irrigation or other ways of blue water-based drought-proofing.

(*a*) *Implementation constraints*

This analysis has been based on very rude assumptions, in order to compare the different world regions. The analysis has, in other words, concentrated on the possibility of mobilizing the extra water needed to support the whole population on the present per capita level, and in addition to allow food production by supplying a total of 25 H. This is an empirical level of water requirement, corresponding to 900 $m^3\ p^{-1}\ yr^{-1}$. There are evidently, however, further constraints that would have to be overcome in order to cover the food production needs. These are (i) water management 'trickiness', using the levels of 10, 20, 40, and 100% mobilization indicated earlier. Included here are the difficulties of balancing the needs for reservoirs and water distribution systems against the side effects on human settlements, landscape, and flora and fauna; (ii) water pollution problems, reducing the utility of the water for irrigation purposes; (iii) the need for trained manpower to perform all the different water management tasks needed for the situation to be sustainable; (iv) the need to finance all the different water resources development projects, their operation and maintenance; and (v) the difficulties in coping with complexity due to bureaucratic problems.

(*b*) *The Malthusian precipice*

This study indicates that the food needs of the world's rapidly growing population will introduce severe problems, either because the rate of growth will be too rapid for the additional water mobilization to be met, or because the overall water demands will grow unrealistically high so that they cannot be met.

Some sort of answer can now be given to the question, implicit in the title of this meeting—are we on the Malthusian precipice? The question refers to land resources, whereas this study has been restricted to water resources. Whatever the answer to the land resource question is, this study indicates that semi-arid regions are indeed on that precipice, but for another reason: not enough water can be mobilized to satisfy the rapidly expanding water requirements of crops. This applies to an overall population of 4.6 billion in Africa and Asia by 2025, mostly in poor countries with limited coping capabilities (ECOSOC 1997). This corresponds to some 55% of the projected world population by 2025, which will have to import food to feed parts of their rapidly growing populations (basically the urban populations).

(*c*) *What should be done to meet the threats?*

It is essential that the indications of this approximate assessment of water constraints to food production in the large dry climate regions with rapid population growth do not generate a feeling of doom. The future studied lies three decades ahead. The study basically shows that the vulnerable countries will have to give up the food self-sufficiency goal. What is needed is a rapid and constructive response to the problems identified decades in advance, leaving plenty of time for compensating action. Evidently, the world's food basket will be in sub-humid and humid regions. These regions will therefore be expected to change radically their agricultural policies to satisfy the emerging needs for intensified crop production.

In order to avert the Malthusian precipice for the dry climate regions discussed in this paper, a major and rapid change is needed also in global agricultural policy and world trade. The question is, can the food needs that cannot be met by production in the regions themselves be met by imports from other better endowed regions? In view of the massive size of the problem that this study suggests, it is extremely urgent to find out where that food should be coming from, and what other potential ways exist to achieve drought-proofing of agriculture rather than traditional irrigation? How much can rainfed agriculture be intensified by benefiting from the non-productive losses now evaporating from wet surfaces of the order of two-thirds or even more of the precipitation in semi-arid regions (Falkenmark & Lundqvist 1995)?

Among the key actions now needed are the following: (i) a global assessment in order to clarify, quantify, and secure the foreseeable regional and inter-regional food transfers—by regional transfers to N. China and by intercontinental transfers for the critical N. Africa–W. Asia–S. Asia belt; (ii) agricultural research: development of methods for drought-proofing in S., E. and W. Africa by rain water harvesting and small-scale runoff collection (the grey zone between irrigated and rainfed agriculture); (iii) evaluation of both the potential, and the limitations, of developing the humid tropics, especially Central Africa, to relieve the problems in other regions in sub-Saharan Africa; and (iv) analysis of the potential of, and the possible complications in, meeting efforts to secure food self-sufficiency by water saving, primarily in the Caucasus and M. Asia/Kazakhstan.

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APPENDIX 1.

Distribution of countries according to physiographic and economic region. Source: Shiklomanov 1996.

region no.	physiographic region	countries included
	Europe	
1	Northern	Denmark, Iceland, Norway, Finland, Sweden, Western and Central
2		Austria, Belgium, United Kingdom, Germany, Netherlands, Poland, Czech Republic, Slovakia, France, Switzerland
3	Southern	Albania, Bulgaria, Hungary, Greece, Spain, Italy, Portugal, Rumania, Yugoslavia (former)
4	FSU, North of European part	Latvia, Lithuania, Estonia, North of European Russia. Byelorussia
5	FSU, South of European part	Moldova, Ukraine, part of Byelorussia, South of European Russia
	North America	
6	Canada and Alaska	Canada, Alaska
7	USA	USA excluding Alaska
8	Central America and the Caribbean	Haiti, Guatemala, Honduras, Dominican Republic, Costa Rica, Cuba, Jamaica, Mexico, Nicaragua, Panama, Puerto Rico, Salvador, Trinidad and Tobago
	Africa	
9	Northern	Algeria, Egypt, Libya, Morocco, Sudan, Tunisia
10	Southern	Angola, Botswana. Mozambique, Namibia, RSA, Zambia, Zimbabwe
11	East	Kenya, Malagasy Republic, Somalia, Tanzania, Ethiopia, Eritrea, Uganda
12	West	Countries of the Sahel zone, Ghana, Guinea, Nigeria, Liberia, Gambia, Senegal, Togo, Benin, Cape Verde, Sierra Leone
13	Central	Gabon, Zaire, Congo, Cameroon, SAR, Rwanda, Burundi
	Asia	
14	North China and Mongolia	China without Yangtze basin, Mongolia, Korea
15	Southern	Bangladesh, Butan, India, Nepal, Pakistan, Sri Lanka
16	Western	Afghanistan, Bahrein, Israel, Iraq, Iran, Jordan, Yemen, Qatar, Cyprus, Kuwait, Lebanon, United Arab Emirates, Oman, Saudi Arabia, Turkey
17	South East	Burma, Vietnam, Indonesia, Cambodia, China (Yangtze basin), Laos, Malaysia, Thailand, Philippines, Japan
18	Central Asia and Kazakhstan	Kazakhstan, Kirghistan, Tadjikistan, Turkmenistan, Uzbekistan
19	Siberia and the Far East	Asian part of Russia
20	Caucasus	Azerbaijan, Armenia, Georgia
	South America	
21	Northern	Venezuela, Guyana, Guyane/France, Colombia, Surinam
22	Eastern	Brazil
23	Western	Peru, Chile, Ecuador
24	Central	Argentina, Bolivia, Paraguay, Uruguay
	Australia/Oceania	
25	Australia	Australia
26	Oceania	Papua New Guinea, New Zealand

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Discussion

J. W. KIJNE (*International Irrigation Management Institute*). Water quality was not mentioned explicitly in the presentation, but when it is considered, it makes the scarcity of good quality water a very urgent matter. Recycled irrigation water contains salts, and reused industrial and municipal waste water contains contaminants, which reduce its use value in irrigation.

Would the high evaporation losses from wet soil suggest that water-demanding crops should not be grown in dry areas with high potential evapotranspiration rates?

M. FALKENMARK. I totally agree that in the next generation of assessment water quality needs to be included—the question is how? Under conditions of water scarcity, the best possible use of the consumptive water use would be desirable. This would have implications for crop selection, but there are of course also non-hydrologic considerations that have to guide crop selection.

B. TARON (*Institute of Soils and Water, Israel*). Increasing irrigation efficiently should be considered. Use of recycled water for irrigation should be considered in calculating regional water balance.

M. FALKENMARK. I appreciate your comments. High irrigation efficiency is of course desirable for economic reasons. Infiltration leakages do not vanish, however, but feed aquifers and rivers available to downstreamers. Recycled water represents an additional water input in the water balance since it contributes to the vertical water flow.

G. MURDOCH (following the Chair's comment that country studies of water utilization are needed). Tony Allen of London University in a recent water budget for 1993 for Egypt has found that out of the water used in the country, 55% comprised irrigation supplies, 19% industrial, domestic and amenity purposes, and as much as 26% was virtual water imported in foodstuffs.

M. FALKENMARK. The virtual water attracts much attention at present. There is of course also virtual water hidden in other imported goods. What makes the difference in interest is the fact that the former is part of the consumptive water use in an arid country, and therefore much more difficult to satisfy than the latter non-consumptive use where most of the water used would go back to the river, available for the downstreamers to reuse. By being a polluting water use import is, however, beneficial for a country in the sense that the imported goods represent an avoided pollution load.

M. V. K. SIVAKUMAR (*WMO*). In addition to the 'blue' and 'green' sources of water in your presentation one might add a third category, the 'fossil water'. Many countries are rich in such water. Niger is one example. Back-of-the-envelope calculations would show that there is a potential to irrigate for more than 100 years from that source. Although today it is uneconomical to pump, by 2050 it may be useful to consider as an additional source of water.

M. FALKENMARK. I agree that fossil water may be seen as an intermittent resource for some countries. An awareness of its sustainability is, however, essential so that long-term planning may include how to replace that resource once it is too expensive to rely upon.

ERIC CRASWELL (*IBSRAM, Bangkok*). How important is the flow irregularity in assessing water availability for food production? Does upper catchment management offer an opportunity to improve downstream water availability?

M. FALKENMARK. The flow irregularity problem is probably especially relevant for dry season crops, depending on irrigation during the low flow season. It has to be remembered though that upper catchment management may be linked to extra water losses if it involves tree plantations, representing runoff foregone for downstreamers. The gain produced by facilitating increased infiltration would basically be the surplus—beyond the extra transpiration generated—that remains for recharging of groundwater aquifers, that might increase the low flow downstream.