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Preface

This report results from the International Expert Meeting on Virtual Water Trade that was held at IHE Delft, the Netherlands, 12-13 December 2002.

The aim of the Expert Meeting was to exchange scientific knowledge on the subject of Virtual Water Trade, to review the state-of-the-art in this field of expertise, to discuss in-depth the various aspects relevant to the subject and to set the agenda for future research. In particular the meeting was used as a preparatory meeting to the Session on ‘Virtual Water Trade and Geopolitics’ to take place at the Third World Water Forum in Japan, March 2003.

The expert meeting in Delft was the first meeting in a series of meetings organised in the framework of phase VI of the International Hydrological Programme (IHP) of UNESCO and WMO. The meetings fit in the programme ‘Water Interactions: Systems at Risk and Social Challenges’, in particular Focal Area 2.4 ‘Methodologies for Integrated River Basin Management’ and Focal Area 4.2 ‘Value of Water’. The series is organised under the auspices of the Dutch and German IHP Committees and the International Water Assessment Centre (IWAC).

After the Forum in Japan, the collection of papers included in this volume will be reprinted, together with the conclusions from the Session on ‘Virtual Water Trade and Geopolitics’, as Report No. 65 of the IHP VI Series ‘Technical Documents in Hydrology’.

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Virtual water: An introduction

A.Y. Hoekstra

1. Introduction

Producing goods and services generally requires water. The water used in the production process of an agricultural or industrial product is called the 'virtual water' contained in the product. For producing 1 kg of grain we need for instance 1000-2000 kg of water, equivalent to 1-2 m^3. Producing livestock products generally requires even more water per kilogram of product. For producing 1 kg of cheese we need for instance 5000-5500 kg of water and for 1 kg of beef we need in average 16000 kg of water (Chapagain and Hoekstra, 2003). According to a recent study by Williams *et al.* (2002), the production of a 32-megabyte computer chip of 2 grams requires 32 kg of water.

If one country exports a water-intensive product to another country, it exports water in virtual form. In this way some countries support other countries in their water needs. Trade of real water between water-rich and water-poor regions is generally impossible due to the large distances and associated costs, but trade in water-intensive products (virtual water trade) is realistic. For water-scarce countries it could therefore be attractive to achieve water security by importing water-intensive products instead of producing all water-demanding products domestically. Reversibly, water-rich countries could profit from their abundance of water resources by producing water-intensive products for export.

The concept of ‘virtual water’ has been introduced by Tony Allan in the early nineties (Allan, 1993; 1994). It took nearly a decade to get global recognition of the importance of the concept for achieving regional and global water security. The first international meeting on the subject was held in December 2002 in Delft, the Netherlands. A special session is devoted to the issue of virtual water trade at the Third World Water Forum in Japan, March 2003.

This paper aims to give a concise introduction to the subject of virtual water and to the research that has been devoted to this subject. First the definition of ‘virtual water’ is reviewed. Second the practical use of the concept is summarised. After that follows a section on the quantification of the virtual water content of products. The subsequent section summarises the efforts of various authors to quantify virtual water trade flows between nations and to draft national virtual water trade balances. The paper concludes with a number of remarks on how to proceed in research and the practical application of the virtual water concept in water policy making.

2. Definition of ‘virtual water’

Virtual water is the water ‘embodied’ in a product, not in real sense, but in virtual sense. It refers to the water needed for the production of the product. Virtual water has also been called ‘embedded water’ or ‘exogenous water’, the latter referring to the fact that import of virtual water into a country means using water that is exogenous to the importing country. Exogenous water is thus to be added to a country’s ‘indigenous water’ (Haddadin, 2003). If it comes to a more precise quantitative definition, principally two different approaches have been proposed and applied so far. In one approach, the virtual water content is defined as the volume of water that was *in reality* used to produce the product. This will depend on the production conditions, including place and time of production and water use efficiency. Producing one kilogram of grain in an arid country for instance can require two or three times more water than producing the same amount in a humid country. In the second approach, one takes a user rather than a producer perspective, and defines the virtual water content of a product as the amount of water that *would have been* required to produce the product at the place where the product is needed. This definition is particularly relevant if one poses the question: how much water do we save if we import a product instead of producing it ourselves?

In the second approach to the definition of ‘virtual water’ a difficulty arises if a product is imported to a place where the product cannot be produced, for instance due to the climate conditions. What for instance is the virtual water content of rice in the Netherlands, where rice is not being produced but imported only? In this case, Renault (2003) proposes to look at the virtual water content of a proper substitute of the product considered. If the definition of virtual water content is approached in this way, one can even argue that seawater fish contains virtual freshwater even though this fish doesn't depend on freshwater at all. In order to compute the virtual freshwater content of seawater fish, Renault (2003) proposes to apply the principle of nutritional equivalence, according to which the virtual water content of a product can be calculated as the virtual water content of an alternative product having the same nutritional value.

A research field very relevant to virtual water analysis is 'life cycle analysis'. In this type of analysis one considers the effects that a product has on its environment over the entire period of its life cycle. Viewed from the life cycle approach, it would make sense not to limit the definition of virtual water to the production stage of the product, but to extend the definition by including the water applied in the use and waste stages of the product. So far none of the researchers in the virtual water field has however taken this approach.

3. The practical value of the virtual water concept

The virtual water concept has basically two major types of practical use.

3.1. Virtual water trade as an instrument to achieve water security and efficient water use

Net import of virtual water in a water-scarce nation can relieve the pressure on the nation's own water resources. *Virtual water can be seen as an alternative source of water.* Using this additional source can be an instrument to achieve regional water security. More firmly stated, and this is the political argument that has been put forward by Tony Allan from the beginning of the virtual water debate, virtual water trade can be an instrument in solving geopolitical problems and even prevent wars over water (Allan, 1998, 2003). Next to the political dimension, there is the economic dimension, equally stressed by Allan (1997, 1999, 2001). The economic argument behind virtual water trade is that, according to international trade theory, nations should export products in which they possess a relative or comparative advantage in production, while they should import products in which they possess a comparative disadvantage (Wichelns, 2001).

Hoekstra and Hung (2002, 2003) argue that – while pricing and technology can be means to increase local water use efficiency and reallocating water at basin scale to its higher-value alternative uses a means to increase water allocation efficiency – virtual water trade between nations can be an instrument to increase 'global water use efficiency'. From an economic point of view it makes sense to produce the water-intensive products demanded in this world in those places where water is most abundantly available. In those places water is cheaper, there are smaller negative externalities to water use, and often less water is needed per unit of product. Virtual water trade from a nation where water productivity is relatively high to a nation where water productivity is relatively low implies that globally *real water savings* are made.

Virtual water trade between or within nations can be seen as an alternative to real, inter-basin water transfers. This is for instance very relevant for China, where major real water transfer schemes (from the south to the north of China) are being considered. Also in the Southern African region, virtual water trade is a realistic, sustainable and more environmentally friendly alternative to real water transfer schemes (Earle and Turton, 2003; Meissner, 2003). With two Asian examples, Nakayama (2003) points out that application of the idea of virtual water trade could seriously impact on the management practice of international river basins.

Renault (2003) notes that the issue of optimal production is not only a matter of wisely choosing the locations of production, but also a matter of proper timing of production. One can try to overcome periods of water shortage by creating artificial water reservoirs, but – as an alternative – one can also store water in its virtual form, e.g. by food storage. This can be a more efficient and more environmentally friendly way of bridging dry periods than building large dams for temporary water storage.

3.2. Water footprints: making the link between consumption patterns and the impacts on water

The second practical use of the virtual water concept lies in the fact that the virtual water content of a product tells something about the environmental impact of consuming this product. Knowing the virtual water content of products creates awareness of the water volumes needed to produce the various goods, thus providing an idea of which goods impact most on the water system and where water savings could be achieved. Hoekstra and Hung (2002) have introduced the concept of the *water footprint*, being the cumulative virtual water content of all goods and services consumed by one individual or by the individuals of one country. In analogy of the ecological footprint (Wackernagel and Rees, 1996; Wackernagel *et al*., 1997), the water footprint can be a strong tool to show people their impact on the natural resources.

4. Quantifying the virtual water content of products

4.1. Virtual water content of various products

Assessing the virtual water content of a product is not an easy task, because there are many factors influencing the amount of water used in a production process. The following factors should at least be considered and preferably provided together with the estimates:

- The place and period (e.g. which year, which season) of production.
- The point of measurement. In case of irrigated crop production, the question is for instance whether one measures water use at the point of water withdrawal or at the field level.
- The production method and associated efficiency of water use. A relevant question is whether water wasted is included in the estimate.
- The method of attributing water inputs into intermediate products to the virtual water content of the final product.

Considering the various studies available, little convergence exists with respect to the general approach taken. Some studies take virtual water content of a product at the production site, other studies consider the hypothetical virtual water content if the product would have been produced at the place where the product is actually consumed. The studies also differ with respect to the point of measurement: some measure at field level, others account for the losses between water withdrawal and application.

For useful information on methods to assess the virtual water content of processed products, the reader is particularly referred to three of the papers included in this volume: Chapagain and Hoekstra (2003), Zimmer and Renault (2003) and Oki *et al.* (2003).

Chapagain and Hoekstra (2003) work with ‘production trees’ that show different product levels. The virtual water content of meat depends for instance on the virtual water content of the animal carcass, which in turn depends on the virtual water content of the live animal. If next to carcass the live animal provides skin for leather as well, the virtual water content of the live animal is divided over carcass and skin according the economic value ratio. The virtual water content of a live animal largely depends on the virtual water content of the feed consumed during the lifetime of the animal. Added to that is the drinking water required during the lifetime of the animal and if relevant other water requirements such as for cleaning stalls.

For the purpose of calculating the virtual water content of products, Zimmer and Renault (2003) make a distinction between primary products (crops), processed products (such as sugar, vegetable oil and alcoholic beverages), transformed products (including animal products), by-products (such as cotton seeds), multiple-products (e.g. coconut trees) and low or non-water consumptive products (e.g. sea fish).

Table 4.1 summarises for a number of products the estimates of the virtual water content by various authors. With respect to terminology it is noted here that, referring to what is called here the ‘virtual water content’ of a product, quite a number of other terms have been and are still being used. Alternative phrasings that have been used are for instance ‘specific water demand’ or ‘water-use intensity’ of a product (Hoekstra, 1998) or ‘unit water requirement’ (Oki *et al*., 2003). Renault (2003) speaks about the ‘virtual water value’ of a product instead of its ‘virtual water content’.

Table 4.1. Virtual water content of a few selected products in m^3/ton. Estimates by different authors.

	Hoekstra & Hung (2003)*	Chapagain & Hoekstra (2003)*	Zimmer and Renault (2003)**	Oki *et al.* (2003)***
Wheat	1150	-	1160	2000
Rice	2656	-	1400	3600
Maize	450	-	710	1900
Potatoes	160	-	105	-
Soybean	2300	-	Egypt: 2750	2500
Beef	-	15977	13500	20700
Pork	-	5906	4600	5900
Poultry	-	2828	4100	4500
Eggs	-	4657	2700	3200
Milk	-	865	790	560
Cheese	-	5288	-	-

* The figures given represent global averages.
** Unless stated otherwise, the data refer to a study for California.
*** Data refer to Japan.

4.2. Water footprints

If compared to other natural resources such as land and energy, little research has been carried out in the area of water if it comes to the assessment of resource use in relation to consumption patterns. A bit of research has been done on the impacts of various diets on water use. Renault (2003), for instance, cites an earlier study according to which a survival diet would require 1 cubic metre of water per capita per day, whereas an animal-product based diet needs some 10 m^3/cap/day. More common diets are ranking from about 2.5 m^3/cap/day for low animal product intake, e.g. in North Africa, to 5 m^3/cap/day for high animal product intake such as in Europe or the USA.

So far only one comprehensive study has been carried out to calculate the water footprints of nations. The results of this study are reported in Hoekstra and Hung (2002, 2003) and Chapagain and Hoekstra (2003). According to this first assessment, countries with a relatively high water footprint per capita, roughly in the order of 2000 m^3/yr per capita, are Belgium and the Netherlands. Countries with a more average footprint, in the order of 1000 m^3/yr per capita, are for instance Japan, Mexico and the USA. Countries with a relatively low water footprint, roughly in the order of 500 m^3/yr per capita, are China, India and Indonesia.

5. Quantifying virtual water trade flows

5.1. International virtual water trade flows

Quantitative research on global virtual water trade has started only very recently. Three independent studies have been carried out: one by IHE in the Netherlands, one by the World Water Council (WWC) in collaboration with the FAO and one by a Japanese research group.

The IHE study has been reported by Hoekstra and Hung (2002, 2003) and Chapagain and Hoekstra (2003). They estimate global virtual water trade between nations to be 1040×10^9 m^3/yr in the period 1995-1999, of which 67% relates to international trade of crops, 23% to trade of livestock and livestock products and 10% to trade of industrial products (Table 5.1). The estimate is based on the virtual water content of the products in the exporting countries.

The study by WWC and FAO is reported by Renault (2003) and Zimmer and Renault (2003). They estimate the global virtual water trade between nations in 2000 at 1340×10^9 m^3, of which 60% relates to trade of vegetal products, 14% to trade of fish and seafood, 13% to trade of animal products and 13% to meat trade (Table 5.2).

Contrary to the IHE study, the estimate is based on the virtual water content of the products in the importing countries.

The Japanese research group (Oki *et al*., 2003) has estimated global virtual water trade from both the exporting countries perspective and the importing countries perspective (Table 5.3). Taking the first perspective, they estimate a global virtual water trade of 683×10^9 m^3/yr. The estimate is lower than the estimate by the IHE research group, which is probably due to the fact that less products were taken into account by the Japanese. Taking the perspective from the importing countries, Oki *et al*. (2003) estimate the global virtual water trade at 1138×10^9 m^3/yr. This estimate is lower than the estimate of WWC-FAO, again due to the fact that less products were taken into account.

The estimates of the three cited studies are all to be seen as conservative estimates, because none of the studies is exhaustive in the product types considered. The three studies provide no more than first rough estimates. However, given that the three studies were carried out independently and that the approaches, source data and assumptions made were partly different, the estimates are surprisingly close to each other.

The three studies show that the world's nations do not have comparable shares in global virtual water trade. Dominant virtual water exporters are the USA, Canada, Australia Argentina and Thailand. Countries with a large net import of virtual water are Japan, Sri Lanka, and Italy. Table 5.4 gives an overview, based on the IHE study, of the largest country contributions to global virtual water trade.

Table 5.1. Assessment of global virtual water trade between nations (period 1995-1999) according to the IHE study.

Global virtual water trade (from perspective of exporting countries)	Volume (Gm^3/yr)	Percentage (%)
- associated with crop trade	695	67
- associated with trade of livestock and livestock products	245	23
- associated with trade of industrial products	100	10
Total	1040	

Table 5.2. Assessment of global virtual water trade between nations (in 2000) according to the WWC-FAO study.

Global virtual water trade (from perspective of importing countries)	Volume (Gm^3/yr)	Percentage (%)
- associated with trade of vegetal products	795	60
- associated with trade of animal products	180	13
- associated with trade of meat	173	13
- associated with trade of fish and sea food	192	14
Total	1340	

Table 5.3. Assessment of global virtual water trade between nations (in 2000) according to the Japanese study.

Global virtual water trade (from perspective of *exporting* countries)	Volume (Gm^3/yr)	Percentage (%)
- associated with trade of cereals	472	69
- associated with trade of soybean	84	12
- associated with trade of meat	127	19
Total	683	

Global virtual water trade (from perspective of *importing* countries)	Volume (Gm^3/yr)	Percentage (%)
- associated with trade of cereals	868	76
- associated with trade of soybean	118	10
- associated with trade of meat	152	13
Total	1138	

Table 5.4. Overview of the largest country contributions to global virtual water trade (period 1995-1999).

Global virtual water trade in relation to crop trade		Global virtual water trade in relation to trade of livestock and livestock products		Total global virtual water trade	
Net import	Net export	Net import	Net export	Net import	Net export
Sri Lanka 12%	Canada + USA 30%	Japan 9%	Australia + New Zealand 18%	Sri Lanka 9%	Canada + USA 24%
Japan 9%	Thailand 7%	Italy 8%	Canada + USA 9%	Japan 9%	Australia + New Zealand 8%

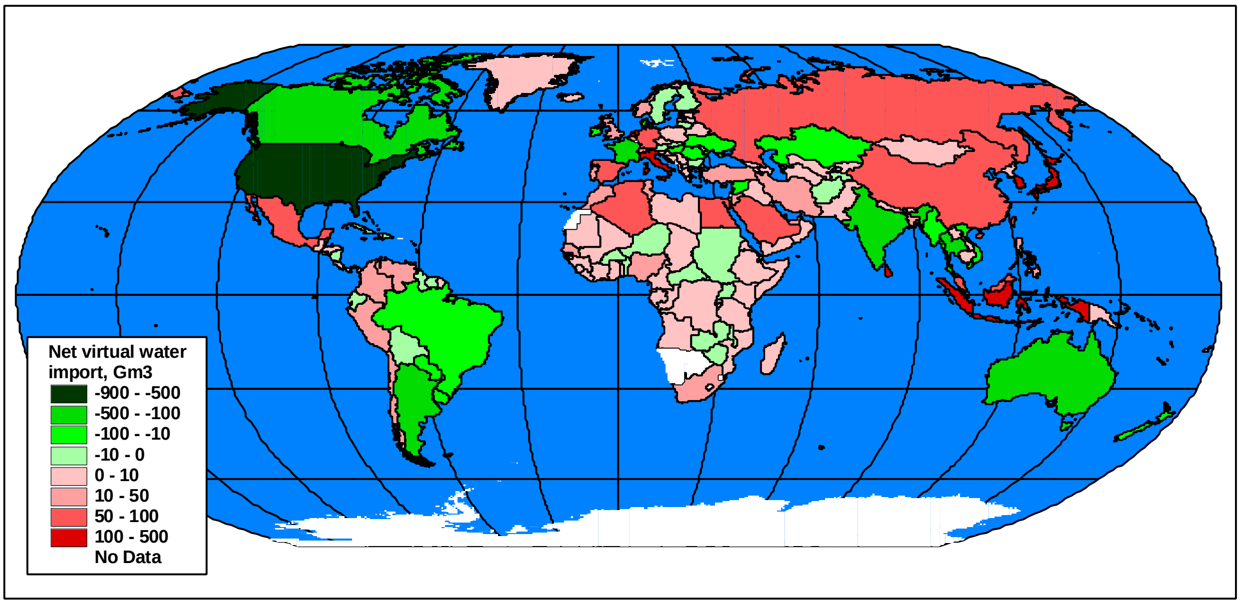

Figure 5.1. National virtual water trade balances over the period 1995-1999. Red represents net import, green net export.

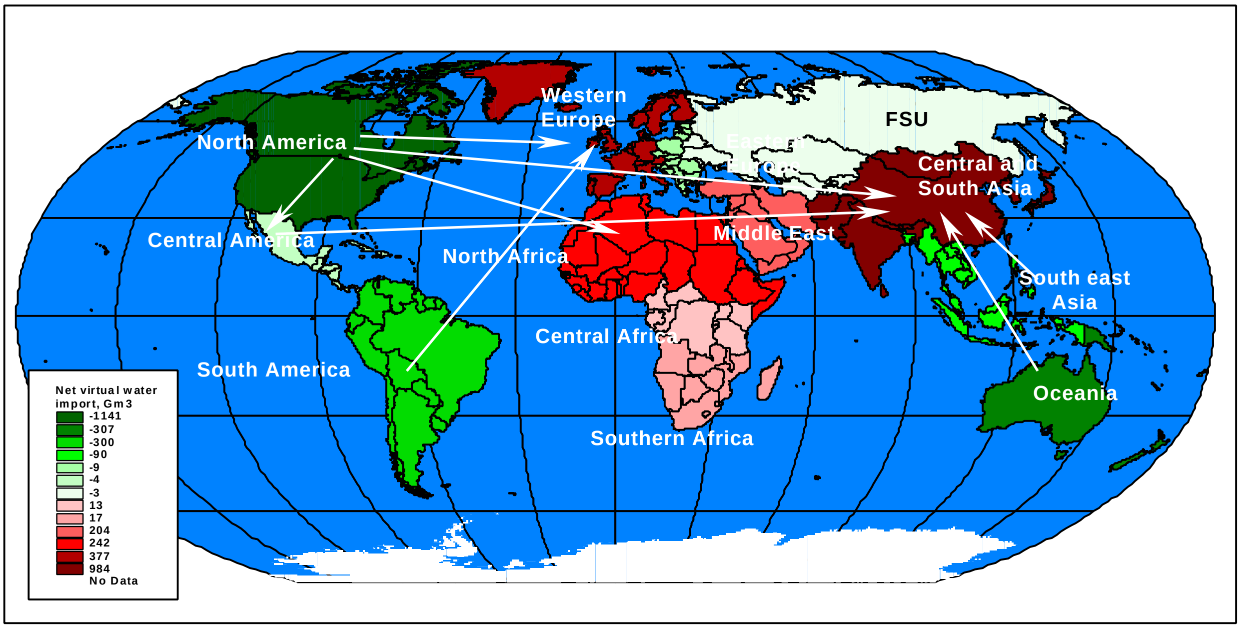

Figure 5.2. Virtual water trade balances of thirteen world regions over the period 1995-1999. The arrows show the largest net virtual water flows between regions (>100 Gm^3).

5.2. National virtual water trade balances

National virtual water trade balances over the period 1995-1999 are shown in Figure 5.1. Countries with net virtual water export are shown in green colour and countries with net virtual water import in red colour. Figure 5.2 shows the virtual water trade balances for thirteen world regions and also shows the largest virtual water trade flows. The world maps show the virtual water trade balances drawn in the IHE study. In Table 5.5 the estimates from this study are compared with the estimates from other studies.

An interesting question is why the virtual water trade balance is positive (net import) for some countries and negative (net export) for others. Yang *et al.* (2003) have studied the relation between per capita water availability in a country and the net cereal import into the country in order to see when international virtual water trade is actually water-scarcity induced. They find what they call a threshold in per capita water availability below which the demand for cereal import and thus the virtual water import increases exponentially with decreasing water resources. Hoekstra and Hung (2002, 2003) have for the same question plotted virtual water import dependency to water scarcity for all nations of the world. Although one would expect some positive correlation between both factors, many countries fall outside the picture expected, that is they have relative high water scarcity but low virtual water import dependency (e.g. Iran, Pakistan) or just the opposite (e.g. Indonesia, Switzerland).

Table 5.5. Virtual water trade balances for the countries where different estimates are available (in billion m^3 per year).

	Chapagain & Hoekstra (2003)	Zimmer & Renault (2003)	Yang & Zehnder (2002)	Oki *et al.* (2003)	Haddadin (2003)	El-Fadel & Maroun (2003)	Yegnes-Botzer (2001)
Algeria							
Net virtual water import	10.5		10.1				
Argentina							
Gross virtual water import	2.4	3					
Gross virtual water export	54.2	69					
Net virtual water import	-51.8	-66					
Australia							
Gross virtual water import	1.8	3					
Gross virtual water export	60.2	85					
Net virtual water import	-58.4	-82					
Brazil							
Gross virtual water import	26.8	19					
Gross virtual water export	38.8	75					
Net virtual water import	-12.0	-57					
Canada							
Gross virtual water import	9.9	19					
Gross virtual water export	74.0	62					
Net virtual water import	-64.1	-43					
China							
Gross virtual water import	34.3	75					
Gross virtual water export	14.9	19					
Net virtual water import	19.4	56					
Colombia							
Gross virtual water import	7.9	8					
Gross virtual water export	1.2	4					
Net virtual water import	6.7	4					
Egypt							
Gross virtual water import	19.4	22	-				
Gross virtual water export	1.0	1	-				
Net virtual water import	18.4	21	16.0				
Ethiopia							
Gross virtual water import	0.35	1					
Gross virtual water export	0.02	0.04					
Net virtual water import	0.33	1					
France							
Gross virtual water import	20.2	43					
Gross virtual water export	42.3	91					
Net virtual water import	-22.1	-48					

	Chapagain & Hoekstra (2003)	Zimmer & Renault (2003)	Yang & Zehnder (2002)	Oki *et al.* (2003)	Haddadin (2003)	El-Fadel & Maroun (2003)	Yegnes-Botzer (2001)
Germany							
Gross virtual water import	37.3	64					
Gross virtual water export	24.1	63					
Net virtual water import	13.1	1					
India							
Gross virtual water import	3.9	31					
Gross virtual water export	38.4	8					
Net virtual water import	-34.5	23					
Indonesia							
Gross virtual water import	24.7	36					
Gross virtual water export	1.4	8					
Net virtual water import	23.3	27					
Israel							
Gross virtual water import	6.4		-				6.90
Gross virtual water export	0.8		-				0.38
Net virtual water import	5.6		5.0				6.52
Japan							
Gross virtual water import	82.9			64.0			
Gross virtual water export	1.1			-			
Net virtual water import	81.8			-			
Jordan							
Gross virtual water import	5.3				6.81		
Gross virtual water export	0.8				-		
Net virtual water import	4.5				-		
Lebanon							
Gross virtual water import	1.93					0.7 - 1.0	
Gross virtual water export	0.03					0.07 - 0.13	
Net virtual water import	1.90						
Libya							
Net virtual water import	1.3		3.0				
Mexico							
Gross virtual water import	29.8	54					
Gross virtual water export	17.9	5					
Net virtual water import	11.9	49					
Morocco							
Net virtual water import	5.7		5.7				
Nigeria							
Gross virtual water import	6.4	8					
Gross virtual water export	1.0	0.3					
Net virtual water import	5.4	7					
Pakistan							
Gross virtual water import	2.64	15					
Gross virtual water export	2.56	4					
Net virtual water import	0.08	11					
Russian Federation							
Gross virtual water import	24.5	49					
Gross virtual water export	14.2	4					
Net virtual water import	10.3	45					
Tunisia							
Net virtual water import	4.0		2.4				
UK							
Gross virtual water import	22.4	43					
Gross virtual water export	19.4	22					
Net virtual water import	3.0	21					
USA							
Gross virtual water import	57.4	65					
Gross virtual water export	221.4	234					
Net virtual water import	-164.0	-169					

5.3. Global water saving related to international virtual water trade

The water productivity – the volume of water required per unit of product – is often higher at the production site than at the consumption site. This means that the *real* virtual water content of a product, which depends on the production conditions at the production site, is often lower than the *hypothetical* virtual water content of the product if the product would have been produced at the consumption site. According to Renault (2003) for instance, trading 1 kg of maize from France to Egypt saves about 0.52 m^3 of water, because the virtual water content of the French maize is about 0.6 m^3/kg, whereas the virtual water content of Egyptian maize is about 1.12 m^3/kg.

Oki *et al.* (2003) estimate that the global water saving due to global food trade amounts to 455×10^9 m^3/yr. Given that the total water use by crops in the world has been estimated at 5400×10^9 m^3/yr (Rockström and Gordon, 2001), this is a saving of about 8%. Oki *et al*. (2003) arrive at their estimate s follows. They estimate that the virtual water content of international food trade flows is 683×10^9 m^3/yr from the point of view of the exporting countries. Producing the traded food products in the importing countries would require 1138×10^9 m^3/yr. The difference makes the global water saving.

5.3. Global virtual water stocks

According to Renault (2003) the stocks of grains worldwide represent a virtual water reservoir of 500×10^9 m^3. This virtual reservoir increases up to 830×10^9 m^3 if stocks of sugar, meat and oil are added. This latter volume amounts to 14% of the capacity of real water reservoirs in the world. If, again according to Renault (2003), living cattle and sheep are accounted for, the total virtual water storage jumps to 4600×10^9 m^3 (77% of real water storage capacity).

6. Conclusion

Knowing that the virtual water concept was proposed by Tony Allan just about ten years ago, one cannot expect that already established methods of research and shared data sets exist. The water footprint concept was proposed by myself not even a year ago. At the International Expert Meeting on Virtual Water Trade held in Delft, the Netherlands in December 2002 it appeared that all experts active in this field of research foresee a rapidly growing importance and application of the virtual water and water footprint concepts. At the very moment however, quantitative research in the field is still very much underdeveloped. The virtual water statistics presented in this volume should be considered as first rough estimates and thus be taken with due caution.

Most papers in this volume focus at virtual water trade related to trade of crops, indeed taking the largest share in global virtual water trade. A few papers include virtual water trade in relation to trade of livestock and livestock products (Chapagain and Hoekstra, 2003; Renault, 2003; Zimmer and Renault, 2003; Haddadin, 2003; Oki *et al.*, 2003). None of the papers includes virtual water trade in relation to trade of industrial products, although Oki *et al.* (2003) made an estimate for Japan and myself made a first very rough global estimate (see Table 5.1).

The studies carried out so far show the importance of including virtual water trade analysis in drafting national water policy plans. Virtual water trade between nations can relieve the pressure on scarce water recourses and contribute to the mitigation of water scarcity at both local and global levels. Virtual water trade should be encouraged to promote water savings for arid countries and at global level through enhancing food security by appropriate agreements and increasing reciprocity in agricultural products trade. It seems wise to include virtual water accounting in any national or regional water and agricultural policy analysis. Common procedures of virtual water accounting and references should therefore be developed and disseminated.

Knowing the national virtual water trade balance is essential for developing a rational national policy with respect to virtual water trade. But for some large countries it might be as relevant to know the internal trade of virtual water within the country. For China for instance, relatively dry in the north and relatively wet in the south, domestic virtual water trade is a relevant issue.

Trade in food and other water-containing products not only concerns virtual water trade but similarly trade in virtual labour, virtual land, etc. Warner (2003) argues therefore to expand virtual water analysis in order to include other, non-water factors. As emphasised by Wichelns (2001, 2003), including virtual water as a policy option requires thorough understanding of the impact of virtual water trade on the local social, economic and cultural situation. A nation's goal with respect to food and water security should be considered within the broader framework of national objectives such as providing national security, promoting economic growth, creating employment for people and reducing poverty. It is clear that further research should be carried out to study the natural, social, and economic implications of using virtual water trade as a strategic instrument in water policy. Instruments are to be developed for analysing the impact of virtual water on local socio-economic and cultural conditions. In addition, building on Tony Allan's work, further analysis is to be made on the geo-political importance of virtual water, the opportunities and threats involved and the associated political processes underlying decision making on application of this concept. As Mori (2003) observes, a set of international norms, principles, rules and decision-making systems are to be designed and successfully converged upon to prevent virtual water trade to lead to even more conflicting situations in the rapidly changing global trading system.

Showing people the virtual water content of the various consumption goods will increase the water awareness of people. The total 'water footprint' of a nation promises to become a useful indicator of a nation's call on the global water resources. At consumers level it is useful to show people's individual footprint as a function of food diet and consumption pattern.

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2

Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade

A.Y. Hoekstra and P.Q. Hung

Abstract

The water that is used in the production process of a commodity is called the 'virtual water' contained in the commodity. International trade of commodities brings along trade of virtual water. The objective of this paper is to quantify the volumes of all virtual water trade flows between nations in the period 1995-1999 and to put the virtual water trade balances of nations within the context of national water needs and water availability. The paper has been limited to the quantification of virtual water trade flows related to international crop trade.

The basic approach has been to multiply international crop trade flows (ton/yr) by their associated virtual water content (m^3/ton). The required crop trade data have been taken from the United Nations Statistics Division in New York. The required data on virtual water content of crops originating from different countries have been estimated on the basis of various FAO databases (CropWat, ClimWat, FAOSTAT).

The calculations show that the global volume of crop-related virtual water trade between nations was 695 Gm^3/yr in average over the period 1995-1999. For comparison: the total water use by crops in the world has been estimated at 5400 Gm^3/yr (Rockström and Gordon, 2001). This means that 13% of the water used for crop production in the world is not used for domestic consumption but for export (in virtual form). This is the global percentage; the situation strongly varies between countries.

Considering the period 1995-1999, the countries with largest net virtual water export are: United States, Canada, Thailand, Argentina, and India. The countries with largest net virtual water import in the same period are: Sri Lanka, Japan, the Netherlands, the Republic of Korea, and China.

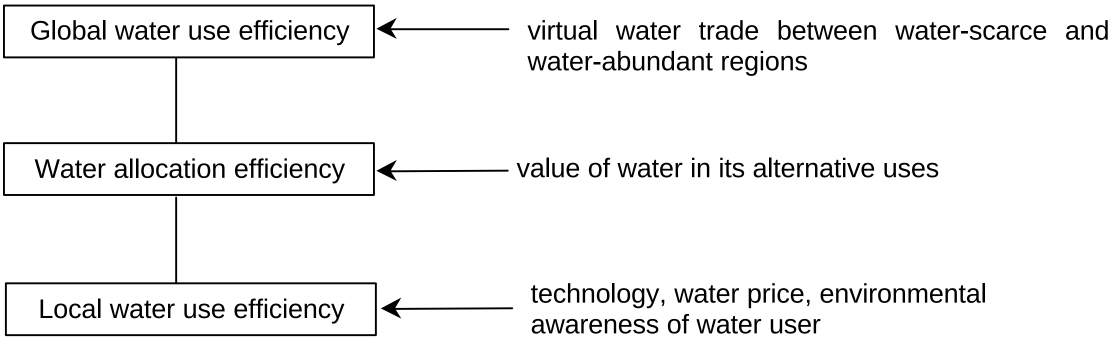
For each nation of the world a ‘water footprint’ has been calculated (a term chosen on the analogy of the ‘ecological footprint’). The water footprint, equal to the sum of the domestic water use and net virtual water import, is proposed here as a measure of a nation’s actual appropriation of the global water resources. It gives a more complete picture than if one looks at domestic water use only, as is being done until date. In addition to the water footprint, indicators are proposed for a nation’s ‘water self-sufficiency’ and a nation’s ‘water dependency’.

1. Introduction

Water should be considered an economic good. Ten years after the Dublin conference this sounds like a mantra for water policy makers. The sentence is repeated again and again, conference after conference. It is suggested that problems of water scarcity, water excess and deterioration of water quality would be solved if the resource ‘water’ were properly treated as an economic good. The logic is clear: clean fresh water is a scarce good and thus should be treated economically. There is an urgent need to develop appropriate concepts and tools to do so.

In dealing with the available water resources in an economically efficient way, there are three different levels at which decisions can be made and improvements be achieved. The first level is the user level, where price and technology play a key role. This is the level where the ‘local water use efficiency’ can be increased by creating awareness among the water users, charging prices based on full marginal cost and by stimulating water-saving technology. Second, at the catchment or river basin level, a choice has to be made on how to allocate the available water resources to the different sectors of economy (including public health and the environment). People allocate water to serve certain purposes, which generally implies that other, alternative purposes are not served. Choices on the allocation of water can be more or less ‘efficient’, depending on the value of water in its alternative uses. At this level we speak of ‘water allocation efficiency’.

Beyond ‘local water use efficiency’ and ‘water allocation efficiency’ there is a level at which one could talk about ‘global water use efficiency’. It is a fact that some regions of the world are water-scarce and other regions are water-abundant. It is also a fact that in some regions there is a low demand for water and in other regions a high demand. Unfortunately there is no general positive relation between water demand and availability. Until recently people have focussed very much on considering how to meet demand based on the available water resources at national or river basin scale. The issue is then how to most efficiently allocate and use the available water. There is no reason to restrict the analysis to that. In a protected economy, a nation will have to achieve its development goals with its own resources. In an open economy, however, a nation can import products that are produced from resources that are scarcely available within the country and export products that are produced with resources that are abundantly available within the country. A water-scarce country can thus aim at importing products that require a lot of water in their production (water-intensive products) and exporting products or services that require less water (water-extensive products). This is called *import of virtual water* (as opposed to import of real water, which is generally too expensive) and will relieve the pressure on the nation’s own water resources. For water-abundant countries an argumentation can be made for *export of virtual water*. Import of water-intensive products by some nations and export of these products by others includes what is called ‘virtual water trade’ between nations.



The overall efficiency in the appropriation of the global water resources can be defined as the ‘sum’ of local water use efficiencies, meso-scale water allocation efficiencies and global water use efficiency. So far most attention of scientists and politicians has gone to local water use efficiency. There is quite some knowledge available and improvements have actually been achieved already. More efficient allocation of water as a means to improved water management has got quite same attention as well, but if it comes to the implementation of improved allocation schemes there is still a long way to go. At the global level, it is even more severe, since basic data on virtual water trade and water dependency of nations are generally even lacking.

The volume of virtual water ‘hidden’ or ‘embodied’ in a particular product is defined as the volume of water used in the production process of that product (Hoekstra, 1998). Not only agricultural products contain virtual water – most studies to date have been limited to the study of virtual water in crops – but also industrial products and services contain virtual water. As an example of virtual water content, one often refers to the virtual water content of grains. It is estimated that for producing one kilogram of grain, grown under rain-fed and favourable climatic conditions, we need about one to two cubic metres of water, which is 1000 to 2000 kg of water. For the same amount of grain, but growing in an arid country, where the climatic conditions are not favourable (high temperature, high evapotranspiration) we need up to 3000 to 5000 kg of water.

If one country exports a water-intensive product to another country, it exports water in virtual form. In this way some countries support other countries in their water needs. For water-scarce countries it could be attractive to achieve water security by importing water-intensive products instead of producing all water-demanding products domestically. Reversibly, water-rich countries could profit from their abundance of water resources by producing water-intensive products for export. Trade of real water between water-rich and water-poor regions is generally impossible due to the large distances and associated costs, but trade in water-intensive products (virtual water trade) is realistic. Virtual water trade between nations and even continents could thus be used as an instrument to improve global water use efficiency and to achieve water security in water-poor regions of the world.

World-wide both politicians and the general public increasingly show interest in the pros and cons of ‘globalisation’ of trade. This can be understood from the fact that increasing global trade implies increased interdependence of nations. The tension in the debate relates to the fact that the game of global competition is played with rules that many see as unfair. Knowing that economically sound water pricing is poorly developed in many regions of the world, this means that many products are put on the world market at a price that does not properly include the cost of the water contained in the product. This leads to situations in which some regions in fact subsidise export of scarce water.

The objectives of this paper are to estimate the amount of water needed to produce crops in different countries of the world, to quantify the volume of virtual water trade flows between nations in the period 1995-1999, and to put the virtual water trade balances of nations within the context of national water needs and water availability. This paper is primarily meant as a data report. We do not pretend to give an in-depth interpretation of the results. Besides, we limit ourselves to virtual water trade in relation to international crop trade, thus excluding virtual water trade related to international trade of livestock products and industrial products. Global virtual water trade in relation to international trade in livestock and livestock products has been analysed in an accompanying paper in this volume (Chapagain and Hoekstra, 2003).

2. Method

2.1. Calculation of specific water demand per crop type

Per crop type, average specific water demand has been calculated separately for each relevant nation on the basis of FAO data on crop water requirements and crop yields:

$$SWD[n,c] = \frac{CWR[n,c]}{CY[n,c]} \tag{1}$$

Here, *SWD* denotes the specific water demand (m^3 ton^{-1}) of crop *c* in country *n*, *CWR* the crop water requirement (m^3 ha^{-1}) and *CY* the crop yield (ton ha^{-1}).

The crop water requirement *CWR* (in m^3 ha^{-1}) is calculated from the accumulated crop evapotranspiration ET_c (in mm/day) over the complete growing period. The crop evapotranspiration ET_c follows from multiplying the ‘reference crop evapotranspiration’ ET_0 with the crop coefficient K_c:

$$ET_c = K_c \times ET_0 \tag{2}$$

The concept of ‘reference crop evapotranspiration’ was introduced by FAO to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. The only factors affecting ET_0 are climatic parameters. The reference crop evapotranspiration ET_0 is defined as the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 12 cm, a fixed crop surface resistance of 70 s m^{-1} and an albedo of 0.23. This reference crop evapotranspiration closely resembles the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with adequate water (Smith *et al.*, 1992). Reference crop evapotranspiration is calculated on the basis of the FAO Penman-Monteith equation (Smith *et al.*, 1992; Allen *et al.*, 1994a, 1994b; Allen *et al.*, 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + g\,\dfrac{900}{T+273}U_2(e_a - e_d)}{\Delta + g\,(1 + 0.34U_2)} \tag{3}$$

in which:

ET_0 = reference crop evapotranspiration [mm day^{-1}];
R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}];
G = soil heat flux [MJ m^{-2} day^{-1}];
T = average air temperature [°C];
U_2 = wind speed measured at 2 m height [m s^{-1}];
e_a = saturation vapour pressure [kPa];
e_d = actual vapour pressure [kPa];
e_a-e_d = vapour pressure deficit [kPa];

D = slope of the vapour pressure curve [kPa °C^{-1}];
g = psychrometric constant [kPa °C^{-1}].

The crop coefficient accounts for the actual crop canopy and aerodynamic resistance relative to the hypothetical reference crop. The crop coefficient serves as an aggregation of the physical and physiological differences between a certain crop and the reference crop.

The overall scheme for the calculation of specific water demand is drawn in Figure 2.1. This figure also shows the next step: the calculation of the virtual water trade flows between nations.

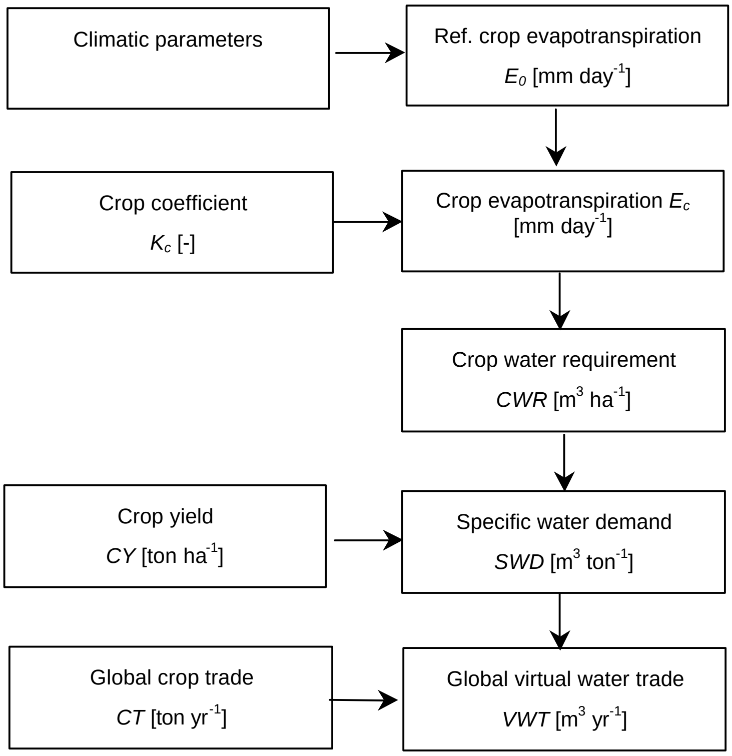


Figure 2.1. Steps in the calculation of global virtual water trade.

2.2. Calculation of virtual water trade flows and the national virtual water trade balance

Virtual water trade flows between nations have been calculated by multiplying international crop trade flows by their associated virtual water content. The latter depends on the specific water demand of the crop in the exporting country where the crop is produced. Virtual water trade is thus calculated as:

$$VWT[n_e, n_i, c, t] = CT[n_e, n_i, c, t] \times SWD[n_e, c] \tag{4}$$

in which VWT denotes the virtual water trade (m^{3}yr^{-1}) from exporting country n_e to importing country n_i in year t as a result of trade in crop c. CT represents the crop trade (ton yr^{-1}) from exporting country n_e to importing country n_i in year t for crop c. SWD represents the specific water demand (m^3 ton^{-1}) of crop c in the exporting country. Above equation assumes that if a certain crop is exported from a certain country, this crop is actually grown in this country (and not in another country from which the crop was just imported for further export). Although a certain error will be made in this way, it is estimated that this error will not substantially influence the overall virtual water trade balance of a country. Besides, it is practically impossible to track the sources of all exported products.

The gross virtual water import to a country n_i is the sum of all imports:

$$GVWI[n_i, t] = \sum_{n_e, c} VWT[n_e, n_i, c, t] \tag{5}$$

The gross virtual water export from a country n_e is the sum of all exports:

$$GVWE[n_e,t] = \sum_{n_i,c} VWT[n_e,n_i,c,t] \tag{6}$$

The net virtual water import of a country is equal to the gross virtual water import minus the gross virtual water export. The virtual water trade balance of country *x* for year *t* can thus be written as:

$$NVWI[x,t] = GVWI[x,t] - GVWE[x,t] \tag{7}$$

where *NVWI* stands for the net virtual water import ($m^3\ yr^{-1}$) to the country. Net virtual water import to a country has either a positive or a negative sign. The latter indicates that there is net virtual water *export* from the country.

2.3. Calculation of a nation's 'water footprint'

The total water use within a country itself is not the right measure of a nation's actual appropriation of the global water resources. In the case of net import of virtual water import into a country, this virtual water volume should be added to the total domestic water use in order to get a picture of a nation's real call on the global water resources. Similarly, in the case of net export of virtual water from a country, this virtual water volume should be subtracted from the volume of domestic water use. The sum of domestic water use and net virtual water import can be seen as a kind of 'water footprint' of a country, on the analogy of the 'ecological footprint' of a nation. In simplified terms, the latter refers to the amount of land needed for the production of the goods and services consumed by the inhabitants of a country. Studies have shown that for some countries the ecological footprint is smaller than the area of the nation's territory, but in other cases much bigger (Wackernagel and Rees, 1996; Wackernagel *et al.*, 1997). The latter means that apparently some nations need land outside their own territory to provide in their goods and services.

The 'water footprint' of a country (expressed as a volume of water per year) is defined as:

$$\text{Water footprint} = WU + NVWI \tag{8}$$

in which *WU* denotes the total domestic water use (m^3yr^{-1}) and *NVWI* the net virtual water import of a country (m^3yr^{-1}). As noted earlier, the latter can have a negative sign as well.

Total domestic water use *WU* should ideally refer to the sum of 'blue' water use (referring to the use of ground- and surface water) and 'green' water use (referring to the use of precipitation). However, since data on green water use on country basis are not easily obtainable, we have provisionally chosen in this paper to limit the definition of water use to blue water use. It should be noted that 'net virtual water import' as defined in the previous section includes both 'blue' and 'green' water.

2.4. Calculation of national water scarcity, water dependency and water self-sufficiency

One would logically assume that a country with high water scarcity would seek to profit from net virtual water import. On the other hand, countries with abundant water resources could make profit by exporting water in virtual form. In order to check this hypothesis we need indices of both water scarcity and virtual water import dependency. Plotting countries in a graph with water scarcity on the x-axis and virtual water import dependency on the y-axis, would expectedly result in some positive relation.

As an index of national water scarcity we use the ratio of total water use to water availability:

$$WS = \frac{WU}{WA} \times 100 \tag{9}$$

In this equation, *WS* denotes national water scarcity (%), *WU* the total water use in the country (m^3yr^{-1}) and *WA* the national water availability (m^3yr^{-1}). Defined in this way, water scarcity will generally range between zero and hundred per cent, but can in exceptional cases (e.g. groundwater mining) be above hundred per cent. As a measure of the national water availability *WA* we take the annual internal renewable water resources, that are the average fresh water resources renewably available over a year from precipitation falling within a country's borders (see for instance Gleick, 1993). As noted in the previous section, total water use *WU* should ideally refer to the sum of blue and green water use, but for practical reasons we have provisionally chosen in this paper to define water scarcity as the ratio of blue water use to water availability, which is generally done by others as well.

Next, we have looked for a proper indicator of 'virtual water import dependency' or 'water dependency' in brief. The indicator should reflect the level to which a nation relies on foreign water resources (through import of water in virtual form). The water dependency *WD* of a nation is in this paper calculated as the ratio of the net virtual water import into a country to the total national water appropriation:

$$WD = \begin{cases} \dfrac{NVWI}{WU + NVWI} \times 100 & \text{if } NVWI \geq 0 \\ \\ 0 & \text{if } NVWI < 0 \end{cases} \qquad (10)$$

The value of the water dependency index will per definition vary between zero and hundred per cent. A value of zero means that gross virtual water import and export are in balance or that there is net virtual water export. If on the other extreme the water dependency of a nation approaches hundred percent, the nation nearly completely relies on virtual water import.

As the counterpart of the water dependency index, the water self-sufficiency index is defined as follows:

$$WSS = \begin{cases} \dfrac{WU}{WU + NVWI} \times 100 & \text{if } NVWI \geq 0 \\ \\ 100 & \text{if } NVWI < 0 \end{cases} \qquad (11)$$

The water self-sufficiency of a nation relates to the water dependency of a nation in the following simple way:

$$WSS = 1 - WD \qquad (12)$$

The level of water self-sufficiency *WSS* denotes the national capability of supplying the water needed for the production of the domestic demand for goods and services. Self-sufficiency is hundred per cent if all the water needed is available and indeed taken from within the own territory. Water self-sufficiently approaches zero if a country heavily relies on virtual water imports.

3. Data sources

Data on crop water requirements are calculated with FAO's CropWat model for Windows, which is available through the web site of FAO (www.fao.org). The CropWat model uses the FAO Penman-Monteith equation for calculating reference crop evapotranspiration as described in the previous section (Clarke *et al.*, 1998). The CropWat model calculates crop water requirement of different crop types on the basis of the following assumptions:

(1) Crops are planted under optimum soil water conditions without any effective rainfall during their life; the crop is developed under irrigation conditions.
(2) Crop evapotranspiration under standard conditions (ET_c), this is the evapotranspiration from disease-free, well-fertilised crops, grown in large fields with 100% coverage.
(3) Crop coefficients are selected depending on the single crop coefficient approach, that means single cropping pattern, not dual or triple cropping pattern.

Climatic data

The climatic data needed as input to CropWat have been taken from FAO's climatic database ClimWat, which is also available through FAO's web site. The ClimWat database contains climatic data for more than hundred countries. For many countries climatic data are available for different climatic stations. As a crude approach, the capital climatic station data have been taken as the country representative. For the countries, where the required climatic input data are not available in ClimWat, the crop water requirement is taken from the guideline of FAO as reported by Gleick (1993). Depending on the country, the authors made an estimate somewhere between the minimum and maximum estimate given in the FAO guideline. If still data were lacking, data were taken from a neighbouring country.

Crop parameters
In the crop directory of the CropWat package sets of crop parameters are available for 24 different crops (Table 3.1). The crop parameters used as input data to CropWat are: the crop coefficients in different crop development stages (initial, middle and late stage), the length of each crop in each development stage, the root depth, and the planting date. For the 14 crops where crop parameters are not available in the CropWat package, crop parameters have been based on Allen *et al*. (1998).

Crop yields
Data on crop yields have been taken from the FAOSTAT database, again available through FAO's web site.

Table 3.1. Availability of crop parameters.

Crops for which crop parameters have been taken from FAO's CropWat package			Crops for which crop parameters have been taken from Allen *et al.* (1998)	
Banana	Maize	Sugar beet	Artichoke	Onion dry
Barley	Mango	Sugar cane	Carrots	Peas
Bean dry	Millet	Sunflower	Cauliflower	Rice
Bean green	Oil palm fruit	Tobacco	Citrus	Safflower
Cabbage	Pepper	Tomato	Cucumber	Spinach
Cotton seeds	Potato	Vegetable	Lettuce	Sweet potato
Grape	Sorghum	Watermelon	Oats	
Groundnut	Soybean	Wheat	Onion green	

Global trade in crops
As a source for the global trade in crops, we have used the 1995-1999 data contained in the Personal Computer Trade Analysis System (PC-TAS), a cd-rom produced by the United Nations Statistics Division (UNSD) in New York in collaboration with the International Trade Centre (ITC) in Geneva. These data are based on the Commodity Trade Statistics Data Base (COMTRADE) of the UNSD. Every year individual countries supply the UNSD with their annual international trade statistics, detailed by commodity and partner country. These data are processed into a standard format with consistent coding and valuation. Commodities are classified according the Harmonised System (HS) classification of the World Customs Organization.

Link between two crop classifications
Specific water demand is calculated for 38 crop types as distinguished by the FAO in CropWat. The Harmonised System (HS) classification used in the COMTRADE database is a much more detailed classification. For our purpose we therefore had to group the commodity classes of the HS classification in order to link to the FAO crop types.

4. Specific water demand per crop type per country

For the calculated crop water requirements for different crops in different countries that are used in this paper, the reader is referred to the full report of this study (Hoekstra and Hung, 2002). The calculated crop water requirements refer to the evapotranspiration under optimal growth conditions. This means that the calculated values are overestimates, because in reality there are often water shortage conditions. On the other hand, the calculated values can also be seen as conservative, because they exclude inevitable losses (e.g. during transport and application of water) and required losses such as drainage. The calculated crop water requirements differ considerably over countries, which is mainly due to the differences in climatic conditions.

Data on country-average actual crop yields in the year 1999 have been retrieved from the FAOSTAT database. Where country specific crop yield data are lacking in FAOSTAT, regional averages have been taken. The differences between countries are here even larger than in the case of the crop water requirements. This is due to the impact of the human factor on the actual crop yields.

Specific water demand (m^3/ton) per crop type has been calculated for different countries by dividing the crop water requirement (m^3/ha) by the crop yield (ton/ha). Because both crop water requirements and crop yields strongly vary between countries, specific water demands vary as well.

It is noted here that the specific water demand data for 1999 have been used in this study to calculate the virtual water trade flows in the whole period 1995-1999 (see next section). This is acceptable because country crop yield data appear not to vary considerably over years.

5. Global trade in virtual water

5.1. International trade in virtual water

The calculation results show that the global volume of crop-related virtual water trade between nations was 695 Gm^3/yr in average over the period 1995-1999. For comparison: the global water withdrawal for agriculture (water use for irrigation) was about 2500 Gm^3/yr in 1995 and 2600 Gm^3/yr in 2000 (Shiklomanov, 1997, p.61). Taking into account the use of rainwater by crops as well, the total water use by crops in the world has been estimated at 5400 Gm^3/yr (Rockström and Gordon, 2001, p.847). This means that 13% of the water used for crop production in the world is not used for domestic consumption but for export (in virtual form). This is the global percentage; the situation strongly varies between countries.

Considering the period 1995-1999, the top-5 list of countries with net virtual water export is: United States, Canada, Thailand, Argentina, and India. The top-5 list of countries in terms of net virtual water import for the same period is: Sri Lanka, Japan, Netherlands, Republic of Korea, and China. Top-30 lists are given in Table 5.1.

National virtual water trade balances over the period 1995-1999 are shown in Figure 5.1. Countries with net virtual water export are shown in green colour and countries with net virtual water import in red colour. It should be noted that some countries, such as Brazil, Syria, Pakistan, Tajikistan, and Uganda have net export of virtual water over the period 1995-1999, but net import of virtual water in one or more particular years in this period. There are also countries that show the reverse, such as the Philippines, the Russian Federation, Uzbekistan, Kyrgyztan, Mongolia, Nicaragua and Mexico.

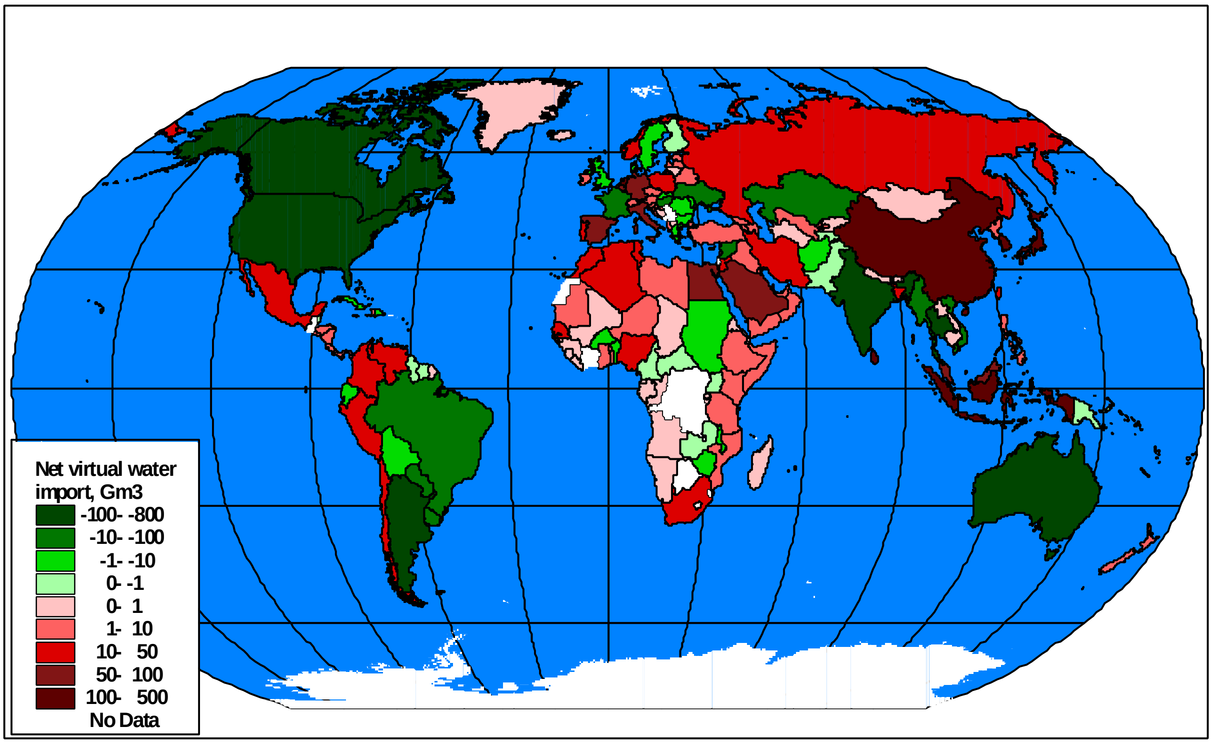


Figure 5.1. National virtual water trade balances over the period 1995-1999.
Green coloured countries have net virtual water export. Red coloured countries have net virtual water import.

Table 5.1. Top-30 of virtual water export countries and top-30 of virtual water import countries (over 1995-1999).

Country	**Net export volume (10^9 m^3)**		**Country**	**Net import volume (10^9 m^3)**
United States	758.3	1	Sri Lanka	428.5
Canada	272.5	2	Japan	297.4
Thailand	233.3	3	Netherlands	147.7
Argentina	226.3	4	Korea Rep.	112.6
India	161.1	5	China	101.9
Australia	145.6	6	Indonesia	101.7
Vietnam	90.2	7	Spain	82.5
France	88.4	8	Egypt	80.2
Guatemala	71.7	9	Germany	67.9
Brazil	45.0	10	Italy	64.3
Paraguay	42.1	11	Belgium	59.6
Kazakhstan	39.2	12	Saudi Arabia	54.4
Ukraine	31.8	13	Malaysia	51.3
Syria	21.5	14	Algeria	49.0
Hungary	19.8	15	Mexico	44.9
Myanmar	17.4	16	Taiwan	35.2
Uruguay	12.1	17	Colombia	33.4
Greece	9.8	18	Portugal	31.1
Dominican Republic	9.7	19	Iran	29.1
Romania	9.1	20	Bangladesh	28.7
Sudan	5.8	21	Morocco	27.7
Bolivia	5.3	22	Peru	27.1
Saint Lucia	5.2	23	Venezuela	24.6
United Kingdom	4.8	24	Nigeria	24.0
Burkina Faso	4.5	25	Israel	23.0
Sweden	4.2	26	Jordan	22.4
Malawi	3.8	27	South Africa	21.8
Dominica	3.1	28	Tunisia	19.3
Benin	3.0	29	Poland	18.8
Slovakia	3.0	30	Singapore	16.9

The calculations show that developed countries generally have a more stable virtual water trade balance than the developing countries. Peak years in virtual water export were for instance found for Thailand, India, Vietnam, Guatemala and Syria. The opposite, the occurrence of peak years with relatively high virtual water import, was found for Sri Lanka and Jordan.

Countries that are relatively close to each other in terms of geography and development level can have a rather different virtual water trade balance. While European countries such as the Netherlands, Belgium, Germany, Spain and Italy import virtual water in the form of crops, France exports a large amount of virtual water. In the Middle East we see that Syria has net export of virtual water related to crop trade, but Jordan and Israel have net import. In Southern Africa, Zimbabwe and Zambia had net export in the period 1995-1999, but South Africa had net import. [It should be noted that the trade balance of Zimbabwe has recently turned due to the recent political and economic developments.] In the regions of the Former Soviet Union, countries such as Kazakhstan and the Ukraine have net export of virtual water, but the Russian Federation has net import.

It is hard to put the data calculated in this study in the context of earlier studies, for the simple reason that few quantitative studies into virtual water trade between nations have been carried out. A few interesting studies have been done for the Middle East and Africa (Allan, 1997, 2001; Wichelns, 2001; Nyagwambo, 1998; Earle, 2001). One study was done by Buchvald for Israel and is available in Hebrew only. The main results of this study are cited in Yegnes-Botzer (2001). According to Buchvald's estimation Israel exported 377 million m^3 of virtual water in 1999 and imported more than 6900 million m^3. The current paper calculates for Israel an export of 700 million m^3 of virtual water in 1999 and an import of 7400 million m^3.

The total volume of crop-related virtual water trade between nations in the period 1995-1999 can for 30% be explained by trade in wheat (Table 5.2). Next come soybeans and rice, which account respectively for 17% and 15% of global crop-related virtual water trade.

Table 5.2. Global virtual water trade between nations by product (Gm^3).

Product	**1995**	**%**	**1996**	**%**	**1997**	**%**	**1998**	**%**	**1999**	**%**	**Total**	**%**
Wheat	181	32.35	215	26.49	254	32.01	203	29.00	197	32.73	1049	30.20
Soybean	103	18.37	108	13.28	125	15.79	122	17.47	135	22.45	593	17.07
Rice	81	14.57	198	24.35	71	8.95	119	16.95	65	10.78	534	15.36
Maize	58	10.40	56	6.93	67	8.51	65	9.22	61	10.14	307	8.85
Raw sugar	9	1.60	68	8.35	119	14.99	42	5.99	13	2.09	250	7.20
Barley	36	6.41	30	3.67	35	4.41	29	4.15	30	5.05	170	4.88
Sunflower	12	2.17	24	2.97	20	2.50	20	2.92	18	2.94	94	2.71
Sorghum	12	2.14	26	3.21	12	1.49	10	1.39	10	1.73	70	2.01
Bananas	11	1.88	16	2.00	15	1.95	15	2.15	11	1.83	68	1.97
Grapes	12	2.07	13	1.64	13	1.65	13	1.87	13	2.24	65	1.86
Oats	9	1.67	10	1.25	11	1.41	9	1.34	10	1.61	50	1.43
Tobacco	5	0.98	10	1.19	11	1.33	13	1.90	7	1.10	46	1.31
Ground-nuts	6	1.10	7	0.84	8	1.02	6	0.90	4	0.70	32	0.91
Peppers	4	0.80	5	0.62	9	1.12	6	0.84	6	1.02	30	0.87
Cotton seeds	5	0.83	5	0.56	5	0.64	6	0.92	7	1.24	28	0.81
Peas	3	0.46	4	0.48	4	0.57	5	0.67	2	0.31	18	0.50
Beans	3	0.47	6	0.68	3	0.35	2	0.36	2	0.38	16	0.45
Potatoes	2	0.40	2	0.26	2	0.31	2	0.33	2	0.37	11	0.33
Onions	2	0.28	3	0.33	2	0.19	2	0.35	1	0.25	10	0.28
Vegetables	1	0.14	1	0.10	1	0.12	4	0.50	1	0.17	7	0.20
Millet	1	0.23	1	0.14	1	0.16	1	0.17	1	0.22	6	0.18
Tomatoes	1	0.14	1	0.12	1	0.13	1	0.17	1	0.19	5	0.15
Palm nuts	1	0.12	1	0.12	1	0.07	1	0.08	0	0.08	3	0.09
Safflower	1	0.12	1	0.09	1	0.08	1	0.09	1	0.09	3	0.09
Cucumbers	0	0.06	1	0.12	1	0.07	0	0.06	0	0.07	3	0.08
Cauliflower	0	0.06	0	0.05	0	0.05	0	0.06	0	0.07	2	0.06
Cabbages	0	0.05	0	0.04	0	0.04	0	0.05	0	0.06	2	0.05
Carrots	0	0.04	0	0.03	0	0.03	0	0.04	0	0.05	1	0.04
Citrus	0	0.04	0	0.03	0	0.02	0	0.01	0	0.01	1	0.02
Artichokes	0	0.02	0	0.01	0	0.01	0	0.01	0	0.02	1	0.01
Lettuce	0	0.01	0	0.01	0	0.01	0	0.01	0	0.02	0	0.01
Sweet potato	0	0.02	0	0.01	0	0.01	0	0.01	0	0.01	0	0.01
Spinach	0	0.00	0	0.00	0	0.00	0	0.00	0	0.01	0	0.00
Grand total	559	100.00	813	100.00	793	100.00	700	100.00	601	100.00	3475	100.00

5.2. Inter-regional trade in virtual water

In order to show virtual water trade between major world regions, the world has been classified into thirteen regions: North America, Central America, South America, Eastern Europe, Western Europe, Central and South Asia, the Middle East, South-east Asia, North Africa, Central Africa, Southern Africa, the Former Soviet Union, and Oceania. Gross virtual water trade between and within regions in the period 1995-1999 is presented in Table 5.3. Net virtual water trade between regions in the same period is shown in Figure 5.2. The largest trade flows have been indicated with arrows. Table 5.4 presents, for each world region, the most important regions for gross import and gross export of virtual water.

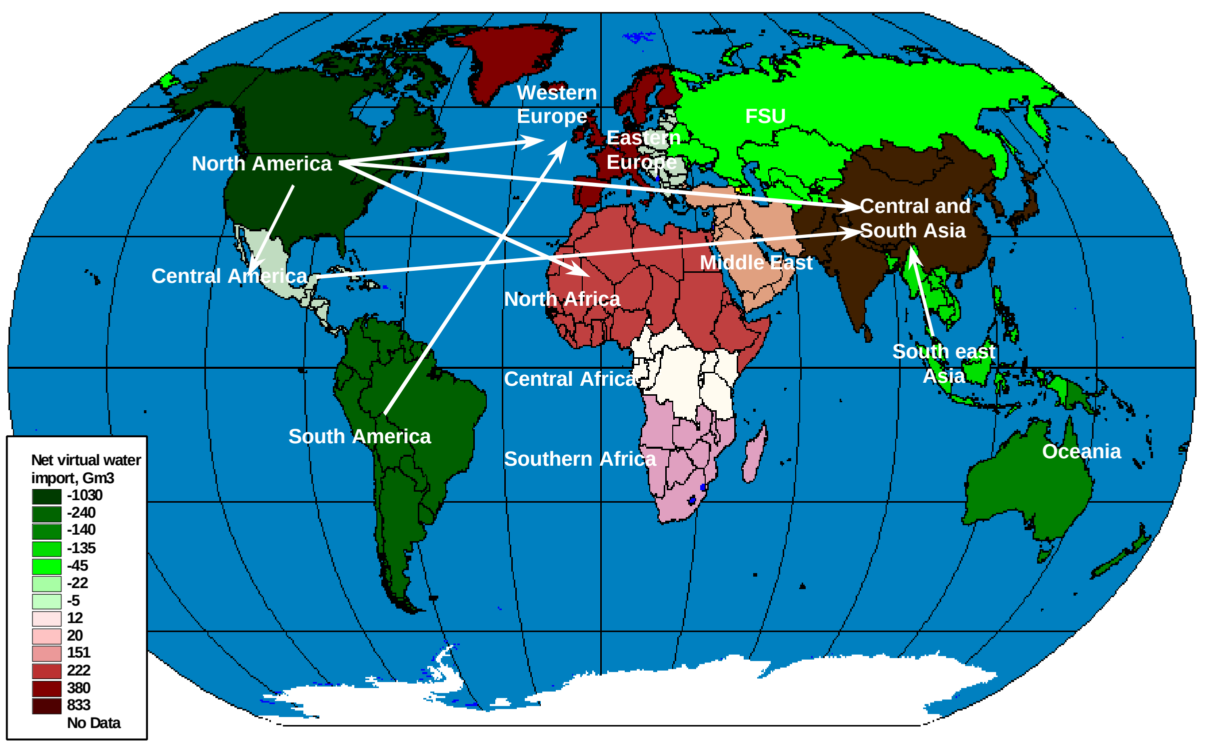


Figure 5.2. Virtual water trade balances of thirteen world regions over the period 1995-1999. Green coloured regions have net virtual water export; red coloured regions have net virtual water import. The arrows show the largest net virtual water flows between regions (>100 Gm3).

Regions with a significant net virtual water import are: Central and South Asia, Western Europe, North Africa, and the Middle East. Two other regions with net virtual water import, but less substantial, are Southern Africa and Central Africa. Regions with substantial net virtual water export are: North America, South America, Oceania, and South-east Asia. Three other regions with net virtual water export, but less substantial, are the FSU, Central America and Eastern Europe. North America is by far the biggest virtual water exporter in the world, while Central and South Asia is by far the biggest virtual water importer. A full ranking of the world regions is given in Table 5.5.

The gross trade in virtual water between countries *within* a region has been calculated by summing up all virtual water imports of the countries of the region that originate from other countries in the same region. [This yields the same result as if we would have added all virtual water exports of the countries in a region that go to other countries in the same region.] The results are shown in the grey-shaded cells of Table 5.3. Western Europe is the region with the biggest internal trade in virtual water. Besides, the trade volume appears to be rather stable over the years. South America is second in the ranking of internal trade volume. Central and South Asia is a rather unstable region if we look at the annual volume of virtual water traded between the countries of the region. Central and South Asia is the largest region in terms of population, so food demand is higher than in the other regions. This explains why the region is the biggest virtual water importer. The virtual water trade between countries within the region is also high, thus the countries within the region highly depend on both countries outside and countries within the region.

Table 5.3. Gross virtual water trade between world regions in the period 1995-1999 (Gm^3). The grey-shaded cells refer to gross trade between countries within *the regions.*

Importer Exporter	Central Africa	Central America	Central & South Asia	Eastern Europe	Middle East	North Africa	North America	Oceania	FSU	Southern Africa	South America	South-east Asia	Western Europe	Total gross export
Central Africa	1.65	0.00	0.11	0.12	0.07	0.05	0.05	0.02	0.01	0.64	0.00	0.05	1.99	3.11
Central America	0.25	4.62	124.52	0.78	0.43	1.53	40.37	0.01	4.29	0.17	2.45	0.41	14.33	189.52
Central and South Asia	3.53	0.67	100.40	3.07	21.64	13.76	3.32	0.40	9.88	9.44	0.87	64.89	17.77	149.25
Eastern Europe	0.02	0.15	2.82	20.40	10.37	7.56	0.56	0.21	5.23	0.12	0.08	0.55	37.42	65.09
Middle East	0.79	0.13	11.56	2.54	25.65	13.21	2.35	0.82	1.21	0.03	0.48	2.72	18.37	54.21
North Africa	0.13	0.15	2.46	1.14	3.74	2.74	4.18	0.00	0.22	0.43	4.61	0.16	13.79	30.99
North America	2.87	153.24	395.21	9.51	63.77	128.51	82.78	4.02	9.65	9.84	88.67	82.80	170.27	1118.38
Oceania	0.81	0.40	83.26	0.07	9.47	9.31	2.69	2.80	0.06	2.84	3.66	31.56	4.41	148.54
FSU	0.01	0.33	8.00	13.06	29.26	3.07	0.96	0.01	48.68	0.00	0.06	0.40	35.00	90.17
Southern Africa	0.73	0.68	5.38	0.50	0.37	0.42	1.74	0.10	0.26	2.78	1.31	1.21	7.66	20.33
South America	1.63	7.16	62.29	7.83	20.26	18.63	13.37	0.34	4.85	2.75	146.73	16.50	191.21	346.83
South-east Asia	1.81	2.14	226.63	2.56	25.76	31.56	12.97	2.63	5.98	11.81	3.45	87.20	11.08	338.38
Western Europe	2.00	2.26	59.53	18.97	20.20	25.45	5.08	0.15	3.89	2.03	1.59	1.78	250.46	142.95
Total gross import	14.60	167.30	981.76	60.16	205.35	253.06	87.62	8.71	45.53	40.11	107.24	203.03	523.28	2698

Table 5.4. Ranking of gross import and gross export regions for each of the thirteen world regions.

Region	Gross import from				Gross export to			
	First	Second	Third	Fourth	First	Second	Third	Fourth
Central Africa	Central and South Asia	North America	Western Europe	South-east Asia	Western Europe	Southern Africa	Eastern Europe	Central and South Asia
North Africa	North America	South-east Asia	Western Europe	South America	Western Europe	South America	North America	Middle East
Southern Africa	South-east Asia	North America	Central and South Asia	Oceania	Western Europe	South and Central Asia	North America	South America
South America	North America	North Africa	South-east Asia	Oceania	Western Europe	Central and South Asia	Middle East	North Africa
Central America	North America	South America	Western Europe	South-east Asia	Central and South Asia	North America	Western Europe	Russian Fed
North America	Central America	Southern Africa	South-east Asia	Western Europe	Central and South Asia	Western Europe	Central America	North Africa
Central Asia	North America	South-east Asia	Central America	Oceania	South-east Asia	Middle East	Western Europe	North Africa
Middle East	North America	Russian Fed	South-east Asia	Central and South Asia	Western Europe	North Africa	Central and South Asia	South-east Asia
South-east Asia	North America	Central and South Asia	Oceania	Southern Africa	Central and South Asia	North Africa	Middle East	North America
Eastern Europe	Western Europe	Russian Fed	North America	South America	Western Europe	Middle East	North Africa	Russian Fed
Western Europe	South America	North America	Eastern Europe	Middle East	Central and South Asia	North Africa	Middle East	Eastern Europe
Oceania	North America	South-east Asia	Middle East	Central and South Asia	Central and South Asia	South-east Asia	Middle East	North Africa
Russian Fed	Central and South Asia	North America	South-east Asia	Eastern Europe	Western Europe	Middle East	Eastern Europe	Central and South Asia

Table 5.5. Ranking of regions in terms of gross virtual water import and gross virtual water export.

Gross virtual water import (1995-1999)		Ranking	Gross virtual water export (1995-1999)	
Region	Gm^3		Region	Gm^3
Central and South Asia	982	1	North America	1118
Western Europe	523	2	South America	347
North Africa	253	3	South-east Asia	338
Middle East	205	4	Central America	190
South-east Asia	203	5	Central and South Asia	149
Central America	167	6	Oceania	149
South America	107	7	Western Europe	143
North America	88	8	FSU	90
Eastern Europe	60	9	Eastern Europe	65
FSU	46	10	Middle East	54
Southern Africa	40	11	North Africa	31
Central Africa	15	12	Southern Africa	20
Oceania	9	13	Central Africa	3

6. Virtual water trade of nations in relation to national water needs and availability

6.1. Water footprints, water scarcity, water self-sufficiency and water dependency of nations

Using the definition given in Section 2.3, a ‘water footprint’ has been calculated for each nation. Next, given the definitions in Section 2.4, indicators of national water scarcity, water self-sufficiency and water dependency have been calculated. The basic data on national water withdrawal and water availability have been taken from Raskin *et al.* (1997). The water availability data refer to the sum of internal and external water resources. The data on net virtual water import per country are taken from this study. The results are shown in Table 6.1. The table provides averages for the period 1995-1999.

Countries with a relatively high water footprint per capita, roughly in the order of 2000 m^3/yr per capita, are Belgium and the Netherlands. Countries with a more average footprint, in the order of 1000 m^3/yr per capita, are for instance Japan, Mexico and the USA. Countries with a relatively low water footprint, in the order of 500 m^3/yr per capita, are China, India and Indonesia.

As always with this kind of statistics, the data should be taken with extreme caution, because of the quality of the underlying source data and the assumptions that had to be made. In assessing the water footprints, we found for instance negative data for a number of countries, including Argentina, Australia, Canada, Guatemala and Thailand. This is obviously impossible. The error follows from the fact that national water use has systematically been underestimated (because green water use was excluded, see Section 2.3). For the countries mentioned, all having net export of virtual water, which is subtracted from the national water use, this could lead to the wrong impression that the overall footprint is negative.

The level of water self-sufficiency has been classified into six categories: 0-20%; 20-50%; 50-70%; 70-90%; 90-99%; and 100%. Table 6.2 lists the countries in each of the categories for the year 1995.

Table 6.1. Water footprints, water scarcity, water self-sufficiency and water dependency of nations (1995-1999).

Country	Population	Water withdrawal (10^6 m^3/yr)	Water availability (10^6 m^3/yr)	Gross virtual water export (10^6 m^3/yr)	Gross virtual water import (10^6 m^3/yr)	Net virtual water import (10^6 m^3/yr)	Water footprint (10^6 m^3/yr per capita)	Water scarcity (%)	Water self-sufficiency (%)	Water dependency (%)
Afghanistan	25765766	35704	50000	287.5	58.5	-229.0	1377	71.4	100.0	0.0
Albania	3387574	356	21300	14.4	277.7	263.2	183	1.7	57.5	42.5
Algeria	29959010	5042	14300	6.9	9810.6	9803.7	496	35.3	34.0	66.0
Andorra	62923			0.0	2.2	2.2				
Angola	67000	628	184000	5.5	173.9	168.4	11886	0.3	78.9	21.1
Anguilla	12771448			0.0	1.3	1.3				
Antigua Barb	67413			0.0	8.8	8.8				
Argentina	36577450	35812	994000	46755.4	1486.9	-45268.4		3.6	100.0	0.0
Armenia	3798845	4109	13300	5.5	316.2	310.6	1163	30.9	93.0	7.0
Aruba	97200			0.0	6.9	6.9				
Australia	18963804	27312	343000	30130.3	1011.0	-29119.3		8.0	100.0	0.0
Austria	8095446	2424	90300	976.1	1281.0	304.9	337	2.7	88.8	11.2
Azerbaijan	7979460	17061	33000	30.0	1004.4	974.4	2260	51.7	94.6	5.4
Bahamas	298331			74.7	24.4	-50.3				
Bahrain	666956	334	290	0.2	137.4	137.1	706	115.2	70.9	29.1
Bangladesh	128837760	26467	2357000	2562.6	8304.6	5742.0	250	1.1	82.2	17.8
Barbados	266262			17.5	119.7	102.2	384			
Belarus	10039496	2979	73800	35.0	1255.9	1220.9	418	4.0	70.9	29.1
Belgium-Lux	10227060	9237	12500	2497.0	14412.4	11915.4	2068	73.9	43.7	56.3
Belize	232143			107.8	22.5	-85.3				
Benin	6112575	154	25800	1077.8	472.6	-605.3		0.6	100.0	0.0
Bermuda	63000			24.4	159.1	134.6	2137			
Bhutan	782229	23	95000	0.0	26.5	26.5	63	0.0	46.5	53.5
Bolivia	8139894	1557	300000	1732.1	674.8	-1057.3	61	0.5	100.0	0.0
Bosnia Herzg	3865576	1354	265000	63.8	238.0	174.2	395	0.5	88.6	11.4
Brazil	168220660	46856	6950000	32161.8	23161.6	-9000.2	225	0.7	100.0	0.0
Brunei Dar.	329686			0.0	323.8	323.8	982			
Bulgaria	8213543	13576	205000	759.7	288.4	-471.4	1595	6.6	100.0	0.0
Burkina Faso	11005226	412	17500	973.4	68.6	-904.7		2.4	100.0	0.0
Burundi	6677800	127	3600	0.3	3.7	3.4	20	3.5	97.4	2.6
Cambodia	11755836	660	498100	27.7	130.1	102.4	65	0.1	86.6	13.4
Cameroon	14557762	500	268000	187.9	175.3	-12.6	33	0.2	100.0	0.0
Canada	30498614	47246	2901000	59308.4	4814.4	-54494.0		1.6	100.0	0.0
Cap Verde		30	300000	0.0	44.4	44.4		0.0	40.3	59.7
Cayman Islds	35000			3.9	96.4	92.5	2644			
Cent.Af.Rep	3657263	85	141000	2.9	1.8	-1.1	23	0.1	100.0	0.0
Chad	7492965	218	43000	0.0	1.4	1.4	29	0.5	99.4	0.6
Chile	15013962	23203	468000	1211.2	3262.6	2051.4	1682	5.0	91.9	8.1
China	1252042000	504315	2800000	10114.9	30550.4	20435.6	419	18.0	96.1	3.9
Christmas Is				0.0	0.0	0.0				
Cocos Islnds				0.0	2.1	2.1				
Colombia	41543956	6031	1070000	865.2	7535.4	6670.2	306	0.6	47.5	52.5
Comoros	544534	13	1020	0.0	39.3	39.3	96	1.3	24.9	75.1

Country	Population	Water withdrawal (10^6 m^3/yr)	Water availability (10^6 m^3/yr)	Gross virtual water export (10^6 m^3/yr)	Gross virtual water import (10^6 m^3/yr)	Net virtual water import (10^6 m^3/yr)	Water footprint (10^6 m^3/yr per capita)	Water scarcity (%)	Water self-sufficiency (%)	Water depen-dency (%)
Congo	49563472	51	832000	6.8	93.4	86.6	3	0.0	37.1	62.9
Congo, D.R.	2934512			4.9	319.9	314.9	107			
Cook Islands				0.0	0.8	0.8				
Costa Rica	3731672	1464	95000	690.0	1947.7	1257.7	729	1.5	53.8	46.2
Cote d’Ivoire	15580058	941	77700	83.5	773.5	690.0	105	1.2	57.7	42.3
Croatia	4395695	1760	265000	346.0	569.9	223.9	451	0.7	88.7	11.3
Cuba	11150144	9585	34500	1304.0	1082.5	-221.5	840	27.8	100.0	0.0
Cyprus	752931			198.9	1263.7	1064.8	1414			
Czech Rep	10283004	2727	58200	761.2	1245.7	484.5	312	4.7	84.9	15.1
Denmark	5318089	1210	13000	1843.6	1382.6	-461.0	141	9.3	100.0	0.0
Djibouti	620352	11	2300	0.2	109.5	109.3	194	0.5	9.1	90.9
Dominica	73040			621.0	2.8	-618.2				
Dominican Rp	8237523	3483	20000	2663.9	731.8	-1932.1	188	17.4	100.0	0.0
Ecuador	12409904	6677	314000	2184.4	1594.2	-590.2	490	2.1	100.0	0.0
Egypt	62782964	55432	68500	901.6	16937.1	16035.5	1138	80.9	77.6	22.4
El Salvador	6155042	1084	19000	94.6	1142.3	1047.7	346	5.7	50.9	49.1
Eq.Guinea	445088			0.0	1.3	1.3				
Eritrea	3988805	240	8800	0.3	74.8	74.6	79	2.7	76.3	23.7
Estonia	1388705	3220	17600	100.4	631.0	530.6	2701	18.3	85.9	14.1
Ethiopia	62782412	2156	110000	22.7	349.1	326.4	40	2.0	86.8	13.2
Faeroe Islds	45000			0.0	1.2	1.2				
Falkland Isl				0.0	0.7	0.7				
Fiji	802087	33	28600	0.0	174.6	174.6	259	0.1	15.9	84.1
Finland	5164368	2243	113000	1091.8	918.9	-172.9	401	2.0	100.0	0.0
Fr. Guiana				0.0	0.4	0.4				
Fr.Polynesia	231362			0.0	13.6	13.6				
France	58656600	38570	198000	27051.4	9376.3	-17675.1	356	19.5	100.0	0.0
Gabon	1198661	78	164000	0.7	100.7	100.0	149	0.0	43.8	56.2
Gambia	1263370	36	8000	164.2	319.3	155.1	151	0.5	18.8	81.2
Georgia	5188007	4054	65200	103.0	308.4	205.4	821	6.2	95.2	4.8
Germany	82109980	47303	171000	9671.3	23260.4	13589.1	742	27.7	77.7	22.3
Ghana	18875980	325	53200	217.5	671.2	453.8	41	0.6	41.7	58.3
Gibraltar				0.0	10.9	10.9				
Greece	10537058	7109	58700	5088.0	3121.4	-1966.6	488	12.1	100.0	0.0
Greenland	56100			0.0	1.2	1.2				
Grenada	97140			8.5	39.0	30.5				
Guadeloupe	151782			6.3	9.9	3.6				
Guatemala	11095762	1501	116000	15536.6	1195.1	-14341.5		1.3	100.0	0.0
Guinea	7250572			40.9	82.1	41.2				
Guinea Bissau	1174665	22	27000	5.4	8.3	2.9	21	0.1	88.3	11.7
Guyana	757015	1501	241000	226.6	67.9	-158.7	1773	0.6	100.0	0.0
Haiti	7803032	47	11000	0.0	389.0	389.0	56	0.4	10.8	89.2
Honduras	6257825	1656	63400	331.7	799.1	467.4	339	2.6	78.0	22.0
Hong Kong				243.0	3111.3	2868.3				

Country	Population	Water withdrawal (10^6 m^3/yr)	Water availability (10^6 m^3/yr)	Gross virtual water export (10^6 m^3/yr)	Gross virtual water import (10^6 m^3/yr)	Net virtual water import (10^6 m^3/yr)	Water footprint (10^6 m^3/yr per capita)	Water scarcity (%)	Water self-sufficiency (%)	Water dependency (%)
Hungary	10221682	6678	120000	4589.6	635.6	-3954.0	266	5.6	100.0	0.0
Iceland	277700	167	168000	1.6	64.8	63.2	829	0.1	72.5	27.5
India	997775760	607227	2085000	34612.3	2413.0	-32199.3	576	29.1	100.0	0.0
Indonesia	207029780	83061	2530000	1139.2	21366.2	20227.0	499	3.3	80.4	19.6
Iran	62762116	85608	117500	803.4	6623.1	5819.7	1457	72.9	93.6	6.4
Iraq	22797032	52259	109200	3.3	1100.7	1097.4	2340	47.9	97.9	2.1
Ireland	3752276	808	50000	201.9	945.8	743.9	414	1.6	52.1	47.9
Israel	6100032	2277	2200	589.9	5188.1	4598.2	1127	103.5	33.1	66.9
Italy	57627528	56362	167000	6762.1	19625.8	12863.7	1201	33.7	81.4	18.6
Jamaica	2604246	414	8300	137.3	392.8	255.5	257	5.0	61.8	38.2
Japan	126624200	91945	547000	188.4	59632.0	59443.6	1196	16.8	60.7	39.3
Jordan	4742815	907	1700	55.0	4536.0	4481.0	1136	53.4	16.8	83.2
Kazakhstan		44138	169400	7876.0	41.8	-7834.2		26.1	100.0	0.0
Kenya	29402552	2454	30200	169.7	970.2	800.5	111	8.1	75.4	24.6
Kiribati	88274			0.0	0.3	0.3				
Korea D P Rp	22141004	16407	67000	2.2	643.0	640.8	770	24.5	96.2	3.8
Korea Rep.	46839720	29558	66100	69.0	22582.6	22513.6	1112	44.7	56.8	43.2
Kuwait	1925635	472	758000	0.1	497.8	497.7	504	0.1	48.7	51.3
Kyrgyzstan	4844973	12953	61700	145.2	192.5	47.3	2683	21.0	99.6	0.4
Lao	5159165	1260	270000	1.7	94.2	92.5	262	0.5	93.2	6.8
Latvia	2408205	673	34000	53.4	301.4	248.0	382	2.0	73.1	26.9
Lebanon	4267969	1178	5600	29.4	776.2	746.8	451	21.0	61.2	38.8
Liberia	3046804	168	232000	1.7	67.5	65.7	77	0.1	71.9	28.1
Libya	5176657	4751	600000	45.4	789.1	743.7	1061	0.8	86.5	13.5
Lithuania	3531820	4416	24200	383.9	500.4	116.5	1283	18.2	97.4	2.6
Macau	431878			0.5	97.0	96.5				
Macedonia	2020714	847	265000	97.9	149.0	51.1	444	0.3	94.3	5.7
Madagascar	15057966	23135	337000	131.7	320.0	188.3	1549	6.9	99.2	0.8
Malawi	10096722	971	18700	786.6	25.9	-760.8	21	5.2	100.0	0.0
Malaysia	22724518	13058	456000	1255.9	11508.3	10252.4	1026	2.9	56.0	44.0
Maldives	269312			0.0	11.6	11.6				
Mali	10588286	1746	100000	14.9	79.8	65.0	171	1.7	96.4	3.6
Malta	387600			45.7	317.4	271.7				
Marshall Is.	51700			0.0	2.1	2.1				
Martinique				11.9	2.1	-9.9				
Mauritania	2579964	1851	11400	0.6	375.7	375.1	863	16.2	83.1	16.9
Mauritius	1173176	390	2200	274.9	564.7	289.7	579	17.7	57.4	42.6
Mexico	96615488	84209	357400	15374.7	24361.3	8986.7	965	23.6	90.4	9.6
Micron, F.St					0.0	9.4				
Moldova Rep.	4291104	3787	13700	455.5	82.8	-372.7	796	27.6	100.0	0.0
Mongolia	2377183	657	24600	10.1	24.6	14.5	282	2.7	97.8	2.2
Montserrat				40.1	0.0	-40.1				
Morocco	28240226	11540	30000	87.4	5617.8	5530.4	604	38.5	67.6	32.4
Mozambique	17331232	655	216000	85.1	337.0	251.9	52	0.3	72.2	27.8

Country	Population	Water withdrawal (10^6 m^3/yr)	Water availability (10^6 m^3/yr)	Gross virtual water export (10^6 m^3/yr)	Gross virtual water import (10^6 m^3/yr)	Net virtual water import (10^6 m^3/yr)	Water footprint (10^6 m^3/yr per capita)	Water scarcity (%)	Water self-sufficiency (%)	Water dependency (%)
Myanmar	47134402	4694	1082000	3501.3	21.1	-3480.2	26	0.4	100.0	0.0
N.Caledonia	208946			0.0	19.7	19.7				
N.Mariana	72000			0.0	5.1	5.1				
Nauru				0.0	0.2	0.2				
Nepal	22507210	3284	170000	19.0	47.6	28.6	147	1.9	99.1	0.9
Neth. Antilles	213148			0.0	52.0	52.0				
Netherlands	15812200	8039	90000	5462.6	35002.3	29539.7	2377	8.9	21.4	78.6
New Zealand	3808760	1992	327000	113.1	1000.6	887.5	756	0.6	69.2	30.8
Nicaragua	4940828	1688	175000	333.1	583.6	250.5	392	1.0	87.1	12.9
Niger	10478080	628	32500	107.9	309.5	201.6	79	1.9	75.7	24.3
Nigeria	123837060	4648	280000	934.4	5796.4	4862.0	77	1.7	48.9	51.1
Norfolk Isld				0.0	0.7	0.7				
Norway	4461300	2077	392000	11.1	2214.7	2203.6	959	0.5	48.5	51.5
Oman	2350640	524	2103	119.6	1228.1	1108.5	694	24.9	32.1	67.9
Pakistan	134871900	278844	468000	2556.8	2547.1	-9.8	2067	59.6	100.0	0.0
Palau	19100			0.0	4.0	4.0				
Panama	2810118	1975	144000	331.1	539.8	208.7	777	1.4	90.4	9.6
Papua N.Guin	5006703	120	801000	20.4	48.9	28.5	30	0.0	80.8	19.2
Paraguay	5358929	541	314000	8768.1	343.0	-8425.1		0.2	100.0	0.0
Peru	25230198	18726	40000	143.5	5566.3	5422.8	957	46.8	77.5	22.5
Philippines	74178100	49035	323000	7242.0	8206.7	964.7	674	15.2	98.1	1.9
Poland	38654642	12349	56200	452.4	4210.1	3757.7	417	22.0	76.7	23.3
Portugal	10028200	7257	69600	529.9	6758.0	6228.1	1345	10.4	53.8	46.2
Qatar	563710	226	195	0.0	59.3	59.3	506	115.9	79.2	20.8
Reunion				13.7	76.1	62.4				
Romania	22469358	25173	208000	2701.2	877.7	-1823.5	1039	12.1	100.0	0.0
Russian Fed	146180880	116422	4498000	12079.6	14534.5	2454.9	813	2.6	97.9	2.1
Rwanda	8304804	809	6300	0.2	93.0	92.9	109	12.8	89.7	10.3
South Africa	42043988	14890	50000	2558.3	6927.6	4369.3	458	29.8	77.3	22.7
S.Vincent-Gr	114120			0.0	56.3	56.3				
Samoa	2851665			1.1	0.7	-0.5				
Sao Tome Prn	144854			0.0	3.4	3.4				
Saudi Arabia	20239432	5092	8760	435.2	11313.3	10878.1	789	58.1	31.9	68.1
Senegal	9279048	1702	39400	43.6	2680.4	2636.8	468	4.3	39.2	60.8
Seychelles	79969			0.0	27.8	27.8				
Sierra Leone	4932139	445	160000	0.6	83.2	82.6	107	0.3	84.3	15.7
Singapore	3957913	211	600	435.2	3839.2	3404.1	913	35.2	5.8	94.2
Slovakia	5395677	1818	30800	977.4	386.6	-590.8	227	5.9	100.0	0.0
Slovenia	1986239	762	265000	21.8	1062.9	1041.1	908	0.3	42.3	57.7
Solomon Isls	416546			1.9	0.6	-1.3				
Somalia	8480576	914	13500	22.7	299.7	277.1	140	6.8	76.7	23.3
Spain	39415552	30968	111300	5621.0	22124.6	16503.6	1204	27.8	65.2	34.8
Sri Lanka	19075498	10410	43200	1633.7	87327.1	85693.3	5038	24.1	10.8	89.2
St.Helena				0.0	1.5	1.5				

Country	Population	Water withdrawal (10^6 m^3/yr)	Water availability (10^6 m^3/yr)	Gross virtual water export (10^6 m^3/yr)	Gross virtual water import (10^6 m^3/yr)	Net virtual water import (10^6 m^3/yr)	Water footprint (10^6 m^3/yr per capita)	Water scarcity (%)	Water self-sufficiency (%)	Water depen-dency (%)
St.Kitts Nev	40920			6.3	7.3	0.9				
St.Lucia	153891			1042.2	1.2	-1041.0				
St.Pier.Miqu				0.0	0.1	0.1				
Sudan	30534126	17800	154000	1712.3	561.3	-1151.1	545	11.6	100.0	0.0
Suriname	415105	518	200000	114.5	27.5	-86.9	1038	0.3	100.0	0.0
Sweden	8864128	2990	180000	1577.2	737.3	-839.9	243	1.7	100.0	0.0
Switz.+Liecht	7145332	1146	50000	162.5	2098.9	1936.5	431	2.3	37.2	62.8
Syria	15798242	10907	53700	5263.2	884.5	-4378.6	413	20.3	100.0	0.0
Taiwan				166.7	7199.1	7032.4				
Tajikistan	6138744	14950	101300	83.7	46.7	-37.1	2429	14.8	100.0	0.0
Tanzania	32902714	1193	89000	283.5	1211.5	928.1	64	1.3	56.2	43.8
Thailand	60275202	35042	179000	50763.3	4098.0	-46665.4		19.6	100.0	0.0
Togo	4392474	115	12000	214.8	851.6	636.8	171	1.0	15.3	84.7
Tonga	99424			0.0	3.7	3.7				
Trinidad Tobago	1293248	163	5100	90.6	679.6	589.0	582	3.2	21.7	78.3
Tunisia	9448461	3391	9000	57.8	3925.1	3867.4	768	37.7	46.7	53.3
Turkey	64341266	36237	193100	8244.4	10297.6	2053.1	595	18.8	94.6	5.4
Turkmenistan	5057637	26186	72000	0.6	57.4	56.9	5189	36.4	99.8	0.2
Turks Ca.Isl				0.0	0.2	0.2				
Uganda	21616208	217	66000	294.8	208.8	-86.0	6	0.3	100.0	0.0
Ukraine	49904874	34623	231000	6832.6	468.9	-6363.8	566	15.0	100.0	0.0
United Arab Em	2800073	657	797	418.1	2109.4	1691.2	839	82.4	28.0	72.0
United Kingdom	59481556	11929	71000	15174.5	14204.1	-970.4	184	16.8	100.0	0.0
Uruguay	3312629	4325	124000	3223.3	821.8	-2401.5	581	3.5	100.0	0.0
USA	278035840	492259	2478000	180924.3	29264.3	-151660.0	1225	19.9	100.0	0.0
Uzbekistan	24394002	91842	129600	123.7	532.7	409.0	3782	70.9	99.6	0.4
Vanuatu	191298			0.0	0.1	0.1				
Venezuela	23705676	4446	1317000	1325.2	6250.8	4925.6	395	0.3	47.4	52.6
Viet Nam	77508750	30851	376000	18185.7	153.8	-18031.9	165	8.2	100.0	0.0
Wallis Fut.I	119622			0.3	0.0	-0.3				
Yemen	17056736	3397	4902	11.5	1448.9	1437.4	283	69.3	70.3	29.7
Yugoslavia		4248	265000	488.3	352.7	-135.6		1.6	100.0	0.0
Zambia	9872326	1759	116000	132.9	34.8	-98.1	168	1.5	100.0	0.0
Zimbabwe	12382668	1527	20000	633.3	115.8	-517.5	82	7.6	100.0	0.0
Area Not Else Specified					92.5	92				
Total	5910605825	3696312	50547567	694918	694918	0				

Table 6.2. Countries categorised into different levels of water self-sufficiency (data for 1995). Note that the numbers in this table do not necessarily correspond to the data in Table 6.1, because Table 6.1 presents 1995-1999 averages, while the current table refers to the 1995 situation.

Level of water self-sufficiency						
0-20%	20-50 %	50-70%	70-90%	90-99 %	100%	
Congo	Algeria	Bahrain	Albania	Afghanistan	Argentina	Malawi
Djibouti	Belgium	Bangladesh	Angola	Armenia	Australia	Moldova
Gambia	Cape Verde	Benin	Bhutan	Azerbaijan	Austria	Mongolia
Haiti	Fiji	Colombia	Cambodia	Belarus	Bolivia	Myanmar
Jordan	Kuwait	Comoros	Egypt	Bosnia	Brazil	Pakistan
Singapore	Netherlands	Costa Rica	Eritrea	Burundi	Bulgaria	Paraguay
Togo	Norway	Côte d'Ivoire	Ethiopia	Chad	Burkina Faso	Philippines
Trinidad Tobago	Oman	El Salvador	Germany	Chile	Cameroon	Papua/NG
	Saudi Arabia	Gabon	Guinea-Bissau	China	Canada	Russia
	Slovenia	Ghana	Honduras	Cuba	Central Africa	Syria
	Switzerland	Ireland	Iceland	Estonia	Croatia	Slovakia
	Tunisia	Israel	Indonesia	Georgia	Czech Rep	Suriname
	UAE	Jamaica	Italy	Iran	Denmark	Sweden
		Japan	Latvia	Iraq	Dominican R.	Thailand
		Kenya	Liberia	Korea	Ecuador	Uganda
		Korea (Rep.)	Libya	Kyrgyzstan	Finland	Ukraine
		Lebanon	Mexico	Laos	France	USA
		Malaysia	New Zealand	Lithuania	Greece	Vietnam
		Mauritius	Niger	Madagascar	Guatemala	Yugoslavia
		Morocco	Nigeria	Mali	Guyana	Romania
		Mozambique	Peru	Mauritania	Hungary	Sudan
		Portugal	Poland	Nepal	India	Uruguay
		Senegal	Qatar	Nicaragua	Kazakhstan	Zambia
		Sierra Leone	Rwanda	Panama	Macedonia	Zimbabwe
		Spain	Somalia	Tajikistan		
		Tanzania	Southern Africa	Turkey		
		UK	Sri Lanka	Turkmenistan		
		Venezuela	Yemen	Uzbekistan		

6.2. The relation between water scarcity and water dependency

One would expect that in general terms there is a positive relationship between water scarcity and water dependency, because high water scarcity will make it attractive to import virtual water and thus become water dependent. One would logically suppose: the higher the scarcity within a country, the more dependency on water in other countries. To test this hypothesis, all countries of the world have been plotted in a scarcity-dependency graph. The result is shown in Figure 6.1. Surprisingly, there seems to be no relation as hypothesised. Let us for simplicity schematise the scarcity-dependency graph into four areas or 'classes'. See Figure 6.2. In Table 6.3 we can see that most of the countries fall in class I.

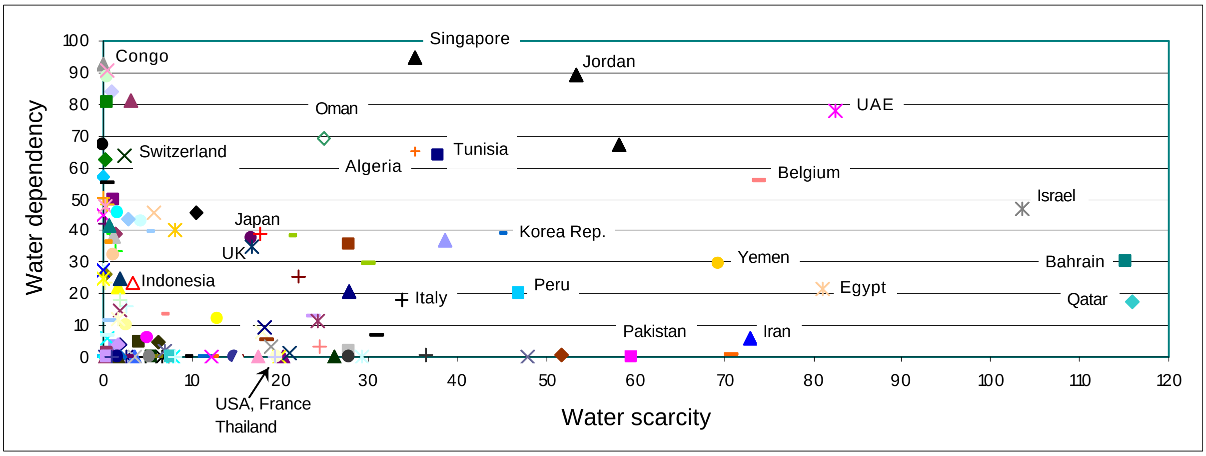


Figure 6.1. Water dependency versus water scarcity for all countries of the world (1995).

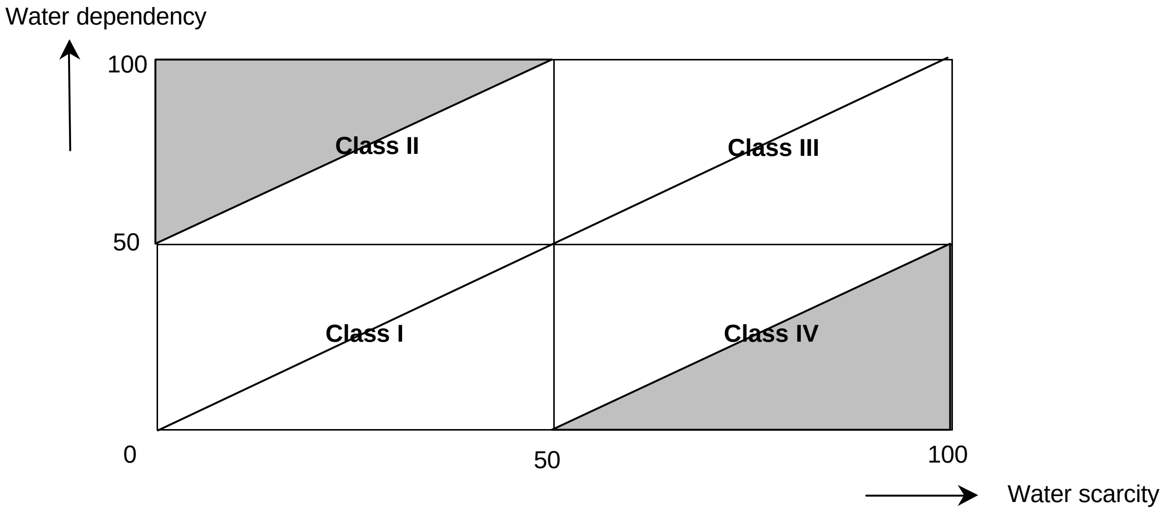


Figure 6.2. Four classes in the scarcity-dependency graph. The grey-shaded areas refer to combinations of water scarcity and water dependency that can difficult be understood at first sight: high water scarcity but low water dependency, and low water scarcity but high water dependency.

Table 6.3. Position of countries in the scarcity-dependency graph. The grey-shaded countries fall in one of the grey-shaded areas of Figure 6.2.

Class I					Class II	Class III	Class IV
Angola	Costa Rica	India	Mexico	South Africa	Algeria	Belgium	Afghanistan
Albania	Cote d'Ivoire	Indonesia	Moldova	Spain	Cape Verde	Jordan	Azerbaijan
Argentina	Croatia	Italy	Mongolia	Sri Lanka	Congo	Saudi Arabia	Bahrain
Armenia	Cuba	Iraq	Morocco	Sudan	Djibouti	UAE	Egypt
Australia	Czech Rep.	Ireland	Mozambique	Suriname	Fiji		Iran
Austria	Denmark	Jamaica	Myanmar	Syria	Gambia		Israel
Bangladesh	Dominican R.	Japan	Nepal	Sweden	Haiti		Pakistan
Belarus	Ecuador	Kazakhstan	New Zealand	Tajikistan	Kuwait		Qatar
Benin	El Salvador	Kenya	Nicaragua	Tanzania	Netherlands		Uzbekistan
Bhutan	Eritrea	Korea (DPR)	Niger	Thailand	Norway		Yemen
Bosnia	Estonia	Korea (Rep.)	Nigeria	Turkey	Oman		
Bolivia	Ethiopia	Kyrgyztan	Panama	Turkmenistan	Singapore		
Brazil	Finland	Laos	Papua/NG	Uganda	Slovenia		
Bulgaria	France	Latvia	Paraguay	UK	Switzerland		
Burkina Faso	Gabon	Lebanon	Peru	Ukraine	Togo		
Burundi	Georgia	Liberia	Philippines	Uruguay	Trinidad		
Canada	Germany	Libya	Poland	USA	Tunisia		
Cambodia	Ghana	Lithuania	Portugal	Venezuela			
Cameroon	Greece	Macedonia	Romania	Vietnam			
Central Africa	Guatemala	Madagascar	Russia	Yugoslavia			
Chad	Guinea-Bissau	Malawi	Rwanda	Zambia			
Chile	Guyana	Malaysia	Senegal	Zimbabwe			
China	Honduras	Mali	Sierra Leone				
Colombia	Hungary	Mauritania	Slovakia				
Comoros	Iceland	Mauritius	Somalia				

7. Concluding remarks

This paper is limited to virtual water trade in relation to *crop* trade between nations. Also other goods contain virtual water, for instance meat, diary products, cotton, paper, etc. In order to get a complete picture of the global virtual water trade flows, also other products than crops have to be taken into account. For an assessment of virtual water trade in relation to international trade of livestock and livestock products the reader is referred to the contribution of Chapagain and Hoekstra in the next paper of this volume.

As stated in the introduction, the current paper is primarily a data report, aimed at disclosing the numbers. A next step is of course to interpret the results and ask the question why the global virtual water trade flows are as they are. What are the explanatory factors behind changes in national virtual water trade balances? What is for instance the relative importance of year-to-year fluctuations in agricultural yields, subsidies in agriculture, national water scarcity, the development of domestic demand for agriculture products? Another next step is to go beyond ‘explanation’ and to study how governments can deliberately interfere in the current national virtual water trade balances in order to achieve higher global water use efficiency.

Knowing the national virtual water trade balance is essential for developing a rational national policy with respect to virtual water trade. But for some large countries it might be as relevant to know the internal trade of virtual water within the country. For China for instance, relatively dry in the north and relatively wet in the south, domestic virtual water trade is a relevant issue.

The method used for the calculation of the virtual water content of different types of crops has a few weak points. As explained, the crop water requirement estimates used in this paper are conservative on the one hand (due to the water losses that are not taken into account), but they are overestimates on the other hand (because they are based on the assumption of optimal growth conditions, an assumption which is generally not met in reality). Improvements to the calculated figures can be made if we could make better estimates of actual specific water use per crop.

Acknowledgement

The authors are thankful to the National Institute of Public Health and the Environment (RIVM), Bilthoven, the Netherlands, which sponsored the work underlying this paper. The research is part of the research programme of Delft Cluster. We would like to thank Ton Bresser (RIVM) and Huub Savenije (UNESCO-IHE) for their valuable inputs.

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3

Virtual water trade: A quantification of virtual water flows between nations in relation to international trade of livestock and livestock products

A.K. Chapagain and A.Y. Hoekstra

Abstract

The transfer of virtual water embedded in various commodities and services that are traded is becoming an important component of water management on global as well as regional level, particularly in the regions where water is scarce. A comprehensive assessment of water management requires a good understanding of the importance of virtual water trade. It is interesting to know the volumes involved, whether these volumes represent a significant part of a nation's water demand, the current tendencies, largest virtual water exporting or importing countries, the products responsible for the most important transfers, etc. So far very little information exists on these issues although some national and regional studies have been produced recently. There is even no clear methodology to evaluate the virtual water content of livestock and livestock products.

This paper aims to develop a methodology to assess the virtual water content of various types of livestock and livestock products and to quantify the virtual water trade flows related to the international trade of livestock and livestock products. The results are then combined with the estimates of virtual water trade associated with international crop trade as reported in Hoekstra and Hung (2002, 2003) to get a comprehensive picture of total virtual water trade in the agricultural sector. The 'water footprint' of each nation is calculated based on the use of domestic water resources and the net import of virtual water. The study covers the period from 1995 to 1999.

The global volume of virtual water trade is estimated to be 940 Gm^3 per year (695 Gm^3/yr from the trade in crops and 245 Gm^3/yr from trade in livestock and livestock products). The countries with the largest net virtual water export are: the United States, Canada, Australia, Argentina and Thailand. The countries with the largest net virtual water import are: Sri Lanka, Japan, Italy, the Republic of Korea and the Netherlands.

1. Introduction

With the Dublin Principles it has been clearly stated that water is a scarce resource and should be used in an economically sound way. The efficiency in water use can be categorised at three broad levels (Hoekstra and Hung, 2002). The lowest level is the user level where efficiency can be improved by adopting structural measures like improving technologies and non-structural measures such as water pricing, awareness raising, etc. The second level of efficiency is related to the allocation and re-allocation of water resources at river basin level to specific, higher-value uses and more equitable use by all stakeholders. Efficiency at this level is generally achieved with government interventions in the form of different policies in the water sector. The highest level of efficiency is related to the inter-basin trade of water. As water is quite a bulky item to transport, trading water in its real form is costly, which is the reason why the concept of virtual water comes into picture.

We define 'virtual water' here as the volume of water required to produce a commodity or service (Allan, 1998, 1999; Hoekstra, 1998). Producing one kilogram of rice in a humid country, say Canada, takes about 1000 litres of water whereas in an arid country such as Israel it takes 2000 litres (Hoekstra and Hung, 2002).

Water use efficiency at global scale can be achieved in a water scarce region by adopting a policy to grow and export products with relatively low virtual water content and import products having higher virtual water content. Increasing water use efficiency at any level is always possible but the cost to do so will increase. Proper economic analysis accounting for the full opportunity cost is necessary to suggest at which level further efficiency improvements can most easily be achieved.

The virtual water embodied in food imports and exports will remain a valid concern for water-short nations seeking to maximize the value of their limited water supplies. The labour, land and capital embodied in the products must also be considered in countries where one or more of those resources is limited (Wichelns, 2001). The trade of virtual water within the agricultural sector is in the form of trade of crop products and the trade of livestock and livestock products. The volume of virtual water trade depends upon the virtual water content of the product traded and the physical volume of trade. Here we define the virtual water content of a product as the amount of water that was required to produce the product in the place of its origin.

The trade of virtual water between nations in relation to the international trade of crops has been quantified by Hoekstra and Hung (2002), see also the paper of Hoekstra and Hung (2003) in this volume. The main objective of the current paper is to assess the volumes of international virtual water trade in relation to the trade of livestock and livestock products. We consider the five separate years in the period 1995-1999. We first estimate the virtual water content of different livestock and livestock products. After having estimated the virtual water trade flows related to trade in livestock and livestock products, we show the total picture of global virtual water trade by including the earlier estimates by Hoekstra and Hung (2002) of virtual water trade related to crop trade. We do not yet include here the virtual water trade related to trade of industrial products.

2. Method

2.1. *Overview*

The virtual water trade related to the trade of livestock or a livestock product is calculated as the trade volume of the product (ton/yr) times its virtual water content (m^3/ton). The virtual water content of each livestock product is dependent upon the animal type from which it originates, the farming system within which the animals are grown and the geographical location (climatic condition) of the production system. Hence, at first, it is necessary to assess the virtual water content of a live animal and then to distribute this over the different products produced from the animal. For simplification it is assumed in the study that a livestock product exported from a certain country is actually fully produced within that country, supposing that an animal feeds, drinks and lives based on domestic resources.

The various steps involved the calculation of global virtual water trade related to international trade of livestock and livestock products are shown in Figure 2.1.

2.2. *Calculation of the virtual water content of live animals*

The virtual water content of an animal at the end of its life span is defined as the total volume of water that was used to grow and process its feed, to provide its drinking water, and to clean its housing or alike. These three components of the virtual water content of a live animal are calculated separately and summed up to get the total virtual water content expressed in terms of cubic meter of water per ton of live animal.

The virtual water content of an animal from the feed consumed consists of two components. The first component is the virtual water embedded inside the various feed ingredients and the second is the mixing water that is required to prepare the feed mix.

The virtual water content from feed crop depends upon the composition of feed of an animal and the total volume of feed consumed by an animal over its lifetime. The virtual water content a crop, also called the specific *water demand* of a crop, is the quantity of water required to produce a certain quantity of the crop and is expressed in m^3/t. It is the ratio of the crop water requirement of a crop in a country (m^3/ha) and the crop yield (t/ha). For each feed crop type, average specific water demand is calculated per country.

For the calculation of the virtual water content of a crop, the same method is used as in Hoekstra & Hung (2002). For assessing the crop water requirements, the CROPWAT model developed by FAO is used. The climate data needed for the crop water requirement calculations are taken from the CLIMWAT database of FAO. It uses the FAO Penman-Monteith equation to calculate the reference crop evapotranspiration (ET_0, mm/d). The crop evapotranspiration (ET_c, mm/d) is calculated using the crop coefficients (K_c), also in-built inside the CROPWAT model for each crop type. The CROPWAT model integrates the ET_c value over the entire growing period to get the total crop water requirement of the crop. The crop yield data are taken from FAOSTAT.

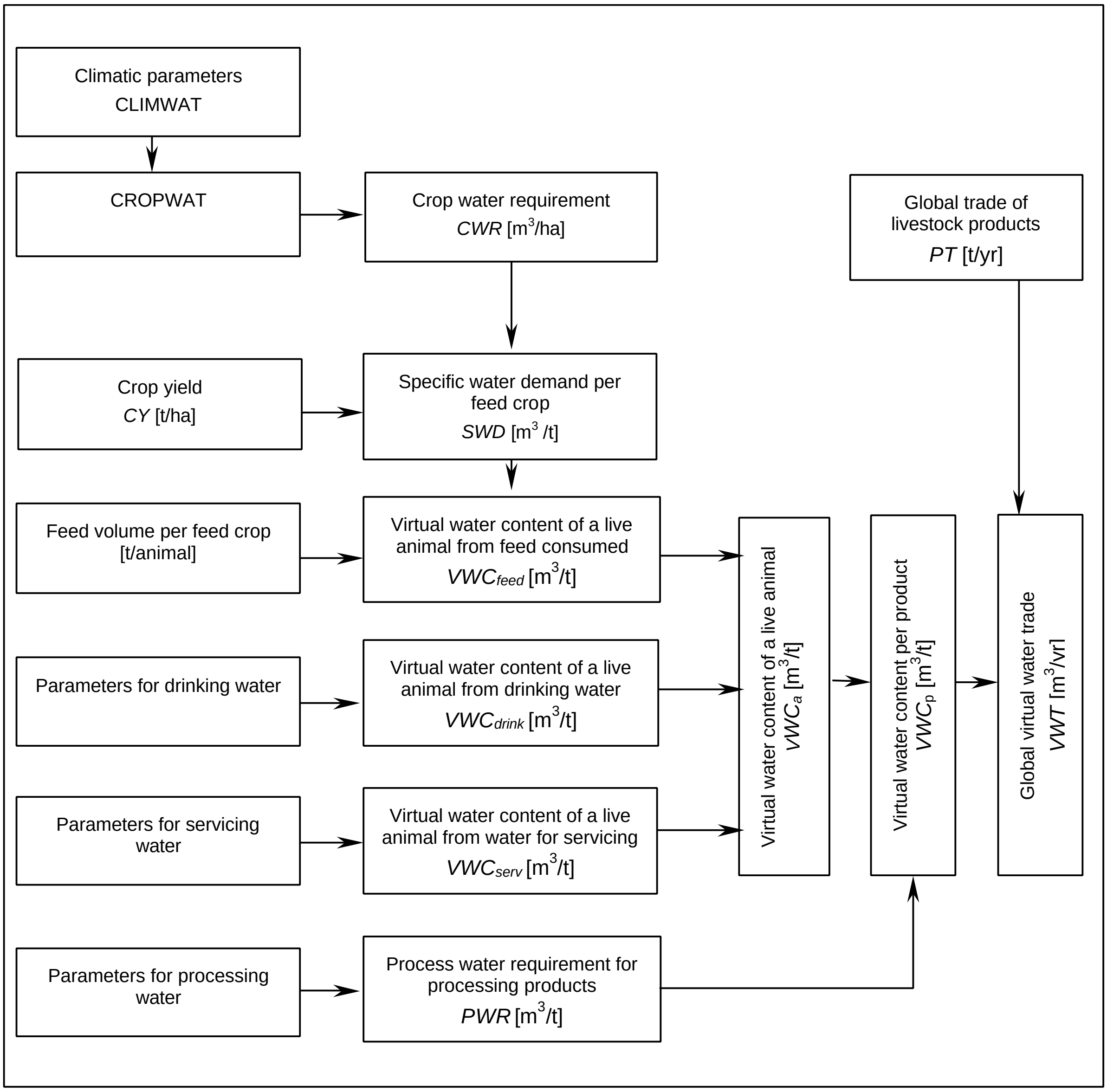

Figure 2.1. Steps in the calculation of global virtual water trade related to international trade of livestock and livestock products.

The virtual water content of an animal originating from drinking is equal to the total volume of water used for drinking water supply, calculated over the entire life span of the animal. We express the virtual water content here in terms of volume of water per ton of live animal.

The virtual water content of an animal originating from servicing is equal to the total volume of water used to clean the farmyard, to wash the animal and other service necessary for maintaining the environment during the entire life span of the animal.

2.3. Calculation of the virtual water content of livestock products

The virtual water content of a live animal contributes to the products made from the animal. We have to distribute the virtual water content of a live animal in such a way to the animal products that neither double counting nor un-accounting occurs. Double counting, for example, would happen if one would attribute the full virtual water content of a cow to its milk first, and then later again to its meat. In order to make a systematic analysis we assume ‘levels of production’. The products produced directly from a live animal are called primary livestock products. For example, live cows are producing milk, carcass and skin as the primary livestock products. Some of these primary livestock products are further processed into so-called secondary products. The primary product milk is for instance further processed into secondary products such as cheese and butter. The primary product carcass is further processed in secondary products such as meat and sausage.

Virtual water content of primary products produced from the processing of live animals

The production of primary products from live animals requires process water. The virtual water content of a primary product thus includes (part of) the virtual water content of the live animal plus the processing water needed. The process water requirement per ton of live animal is the volume of water needed to process one ton of live animal to get different primary products (m3/t of live animal).

For attributing the total virtual water content of the live animal and the process water requirement to the primary products we introduce the terms ‘product fraction’ and ‘value fraction’. The product fraction (*pf*) of a product is defined as the amount of primary product (in ton) obtained per ton of live animal. For example, if a beef cow of 500 kg live weight produces 300 kg of carcass, the product fraction for carcass is 0.60. The ‘value fraction’ (*vf*) is the ratio of the market value of one product from the animal to the sum of the market values of all products from the animal. The sum of virtual water content of a live animal and the process water is distributed over different primary products based on their value fraction. This volume of water is then divided by the product fraction of the primary product to get the virtual water content of the particular primary product (m^3/ton of primary product).

Virtual water content of secondary products produced from primary products

The production of secondary products from primary products also requires some process water. The virtual water content of a secondary product is composed of part of virtual water content of primary product and the process water needed. The product fraction is now defined as the ratio of the amount of the secondary product (in ton) obtained per ton of primary product. Similarly the value fraction is now defined as the ratio of the market value of a secondary product from the root product to the total market value of all secondary products from the primary product.

Likewise, we can calculate the virtual water content for products at tertiary level or even more downwards in the product tree.

Illustration for the calculation of the virtual water content of ‘bovine products’

The method to calculate the virtual water content of live animal and livestock products is illustrated with one simple example of bovines (live animals) producing carcass and raw skin as the primary products, and meat, skin and sausage as the secondary products under industrial farming system in Canada. In this group we mainly deal with cows grown for beef production. The average data are taken for the calculation are: live weight of a fully grown cow (545 kg), drinking water requirements (for an adult cow, 38 l/d/animal, for a clave of 5 month age, 5 l/d/animal), service water requirements (for an adult cow, 11 l/d/animal, for a clave of 5 month age, 2 l/d/animal), animal age at the time of slaughter (36 month).

The feed data of the 'beef cattle' and the 'beef replacement heifers (<1yr)' are taken from the Canada Statistics Division (2002). The *specific water demand* for different types of crop for Canada is taken from Hoekstra and Hung (2002). Mixing water requirement for the feed preparation is assumed to be 50% of the total volume of feed consumed. Assuming a linear growth in feed consumption with age, the average feed volumes are calculated. These feed volumes are multiplied by specific water demands of corresponding crop type to get the volume of virtual water consumed by the animal per day.

The virtual water from feed, drinking and servicing are integrated over the life span of the animal to get the total volume of virtual water content of a live animal, which comes out to be 5243 m^3/animal. As the live weight of the animal is 0.545 ton, the virtual water content of bovine cattle in Canada is equivalent to 9619 m^3/t of live animal. If it is traded alive, the total virtual water traded is equal to 9619 m^3/t.

The live animal may also be traded after first level of processing producing ‘carcass’, ‘offals’ and ‘skin’ as primary products. The *product fractions* and *value fractions* for these primary products are calculated in Table 2.1

Table 2.1. Calculation of product fraction and value fraction of primary products from a bovine.

	Carcass	Offal	Skin
Quantity of primary product (in ton) per ton of live animal, *product fraction*	0.60 t/t of live animal	0.15 t/t of live animal	0.08 t/t of live animal
Market value (*x* 10^3US$/t)	= 3.159	= 2.013	= 2.091
Individual value (*x* 10^3US$)	=0.60x3.159 = 1.8954	= 0.15 x 2.013= 0.3021	=0.08x2.091= 0.1673
Total value obtained per ton of live animal (*x* 10^3US$)	= 1.8954 + 0.3021+0.1673 = 2.3646		
Value fraction, *vf*	= 1.8954/2.3646 = 0. 802	= 0.3021/2.3646 = 0.128	= 0.2091/2.3646 = 0.0071

The quantity of water used in the abattoir for processing a bovine in Canada, *process water requirement* [*Canada, bovine*] is 10 m^3/t of live weight of the animal. The virtual water contents of these primary products are calculated as:

$$VWC[Canada, carcass] = \left\lfloor \frac{(9629+10)\times 0.802]}{0.60} \right\rfloor \quad = 12864\ m^3/t$$

$$VWC[Canada, offal] = \left\lfloor \frac{(9629+10)\times 0.128]}{0.15} \right\rfloor \quad = 8199\ m^3/t$$

$$VWC[Canada, skin] = \left\lfloor \frac{(9629+10)\times 0.071]}{0.08} \right\rfloor \quad = 8513\ m^3/t$$

The primary product carcass may further be processed producing secondary products like ‘carcass frozen’, ‘bovine cuts bone in’, and ‘meat cured’. As the production is mutually exclusive, we have only one product at one time. Hence the value fraction is 1.0 for these products (Table 2.2).

Table 2.2. Calculation of value fraction, product fraction of secondary products from bovine carcass.

	Carcass frozen	Bovine cuts, bone in	Meat cured
Quantity per ton of carcass, *pf*	1.00	0.98	0.95
Value fraction, *vf*	1	1	1
Process water requirement, m^3/t	0	2	5

The virtual water contents of these secondary products are calculated as:

$$VWC[Canada, carcass\ frozen] = \left\lfloor \frac{(12864+0)\times 1]}{1} \right\rfloor \quad = 12864\ m^3/t$$

$$VWC[Canada, bovinecuts] = \left\lfloor \frac{(12864+0)\times 1]}{0.95} \right\rfloor \quad = 13541\ m^3/t$$

$$VWC[Canada, meat\,cured] = \left\lfloor \frac{(12864+5)\times 1]}{0.98} \right\rfloor \quad = 13132\ m^3/t$$

The virtual water content of secondary products from other two primary products can also be derived as above. If these products are further processed before trade, the process water requirement should be added and the approach is again similar as described above. For example, 1 ton of raw skin produces only 0.85t of refined skin. It requires 2 m^3 of water per ton of raw skin. Thus the virtual water content of the refined skin is calculated as,

$$VWC[Canada, refined\ skin] = \left[\frac{[(8513+2)\times 1]}{0.85}\right] \qquad = 10047\ m^3/t$$

The above illustration is schematically presented in Figure 2.2.

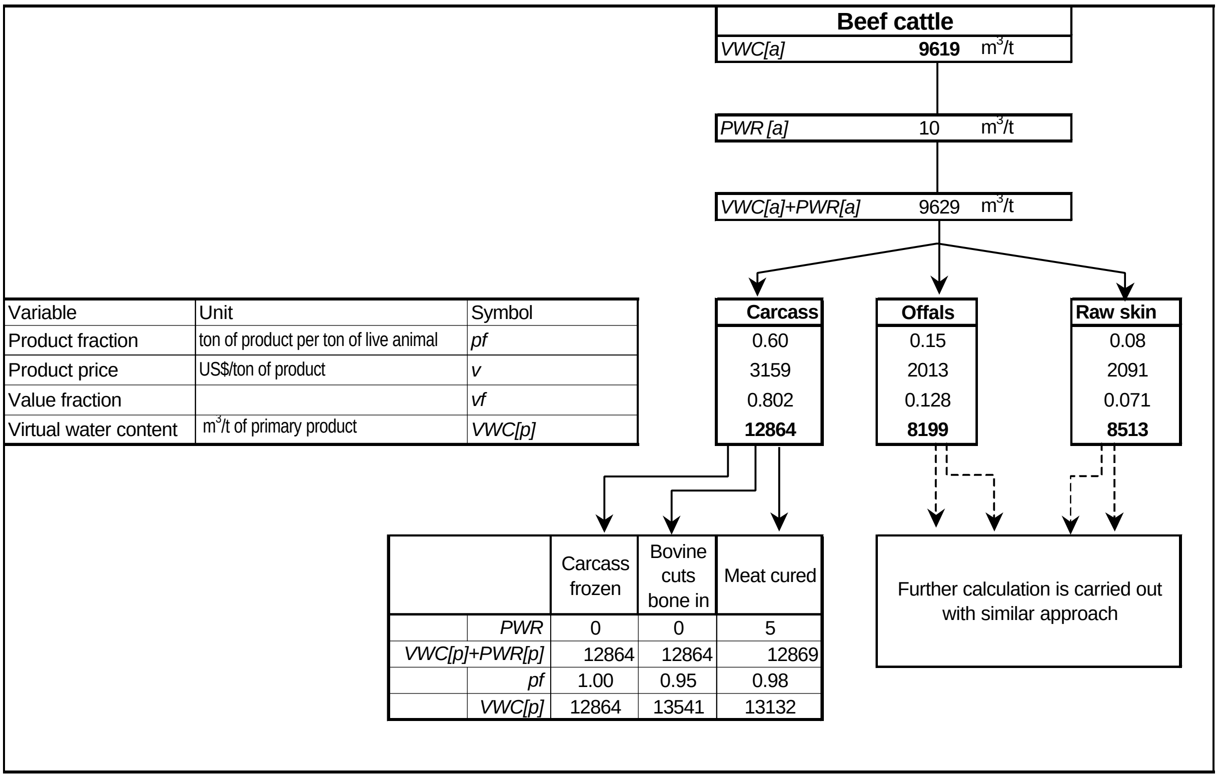

Figure 2.2. Schematic diagram for the calculation of virtual water content of products from a beef cattle.

3. Data sources

Data on global trade of livestock and livestock products are taken from the database produced by the United Nations Statistics Division (UNSD) in New York in collaboration with the International Trade Centre (ITC) in Geneva. The data are available in the form of a CDROM 'PC-TAS' (Personal Computer Trade Analysis System) for the period of 1995 up to 1999. The PCTAS database covers the international trade of 146 livestock and livestock products.

In this study the products are grouped together based on the animals from which they are produced. The nine major groups distinguished are: beef cattle, dairy cow, swine, sheep, horse, layer, goat, poultry/fowls, and 'others'. Animal production parameters such as feed composition, drinking water and service water volumes, product yield etc. depend on the farming system used. For that reason, we distinguish a limited number of farming systems in this study, based on the FAO classification of livestock production system (FAO, 1995). The systems are defined into three broad categories: grazing system, mixed system and industrial system. In terms of total production, grazing systems supply only 9% of the global meat production. Mixed farming systems produce the largest share of total meat (54%) and milk (90%) and mixed farming is the main system for smallholder farmers in many developing countries. Industrial systems provide >50% of the global pork and poultry meat production and 10% beef and mutton production (FAO, 1995). Here we presuppose a crude relation between the *gross national income (GNI) per capita* and the existence of the three different farming systems. For countries with high *GNI per capita*, the industrial farming system is dominant. For countries with low *GNI per capita,* the grazing system is dominant. The countries within these two ranges of *GNI per capita,* mixed farming system are assumed to be the dominant one. The data on *GNI per capita* are taken from World Bank (2002).

The various animal production parameters for relevant animal types are given in Table 3.1. For mixed farming system we have taken the average of the other two systems.

Table 3.1. Animal production parameters for industrial and grazing livestock systems.

Animal group	Parameter	Grazing system	Industrial system
Dairy cattle	Calves (age in yrs.)	0-1	0-1
	Heifers (age in yrs.)	1-3	1-3
	Milking cows (age in yrs.)	3-10	3-10
	Milk production per lactation (kg/yr)	2500	7400
	Number of lactations	7	7
	Live weight of finishing animal (ton)	0.270	0.454
	Carcass yield (ton/ live animal)	0.18	0.25
Beef cattle	Calves (age in months)	5	5
	Finishing cows (age in month)	24	36
	Live weight of finishing animal (ton)	0.300	0.545
	Carcass yield (t/ live animal)	0.200	0.330
Swine	Piglet (age in months)	0.5	0.5
	Adult (age in months)	12	10
	Live weight of finishing animal (ton)	0.090	0.118
	Carcass yield (ton/ live animal)	0.055	0.086
Sheep	5lb baby (age in months)	0.2	0.2
	Adult (age in months)	24	18
	Live weight of finishing animal (ton)	0.04	0.053
	Carcass yield (t/ live animal)	0.032	0.043
Goat	5lb baby (age in months)	0.2	0.2
	Adult (age in months)	30	24
	Live weight of finishing animal (ton)	0.035	0.040
	Carcass yield (ton/ live animal)	0.027	0.032
Broiler	Slaughtered age (weeks)	15	10
	Live weight (kg)	1.80	2.20
	Dressed weight (kg)	1.40	1.60
Layer	Brooding age (week)	1	1
	Start of laying eggs (week)	25	22
	Slaughtered age (week)	75	75
	Egg production (no./yr)	120	300
	Live weight (kg)	1.50	2.00
	Dressed weight (kg)	1.10	1.60
	Weight of eggs (gram)	35	50

Source: WUR, 2002; FAO, 2002a; USDA, 1998; USDA, 2002c.

The available feed composition data for the different livestock farming system are normally expressed in terms of its nutrient value. In this study we use Canadian data (Statistics Canada, 2002) on feed composition on industrial livestock production system. Data on feed composition in grazing systems are based on a number of different sources (USDA, 1998, 2002a, 2002b, 2002d; FAO, 1987; FAO, 2002b; Haan, 1998; Blackburn, 1998; Anderson, 2002; Boleman et al., 2001; Pirelli et al., 2000; Paris, 2002). The specific water demands per crop type per country are have been taken from Hoekstra and Hung (2002).

The drinking water requirement of an animal is dependent upon different variables, such as breed type, age, weight, farming system, ambient temperature etc. It is assumed that the demand increases linearly with age and becomes constant after the age of puberty. The daily drinking water data are collected for different animals and their major breeds from a wide range of sources. The average data are taken from the most often quoted ranges of data for major breeds and are presented in Table 3.2.

Table 3.2. Daily drinking water demand for different animals under different farming system in litre per animal per day.

Animal	Age cohort	Drinking water requirement	
		Industrial system	Grazing system
Dairy cattle	Calves	5-23	4-18
	Heifers	26-70	18-30
	Milking cows	70	40
Beef cattle	Calves	5	5
	Finishing cows	38	22
Swine	Piglet	1.8	1.8
	Adult	14	8
Sheep	5lbs baby	0.38	0.30
	Adult	7.6	6.00
Goat	5lbs baby	0.38	0.30
	Adult	3.8	3.5
Broiler	Brooding	0.02	0.02
	Adult	0.18	0.18
Layer	Brooding	0.02	0.02
	Start of laying eggs	0.30	0.30
	Slaughtered	0.30	0.30

Source: Pallas, 1986; Irwin, 1992; Alberta, 1996; AAFC, 2000; Gregorica, 2000; Jermar, 1987; Kammerer, 1982; Kollar K.L. and MacAuley, 1980; USAEP, 2002; World Bank, 1996; NCDENR, 2002; NDSU, 1992; UMCE, 2002; Looper and Waldner, 2000; Alberta, 2000.

There is very little literature on the water requirement for the servicing. Some sources simply cover these water requirements under the drinking water requirements. There are not sufficient data covering all the countries and different animals. We have primarily used data from Alberta (1996) and Jermar (1987). Average values have been taken wherever possible and if there were no data at all a simple reasonable guess has been made.

For a certain type of product the process water requirement is more or less comparable across different countries. There are minor variations based on the efficiencies of water use depending on recycle percentage, cooling processes etc. As the process water carries smaller share to the virtual water content of a livestock product, it is safe to assume one value for a product across the globe. These data are collected from various sourcess (Kollar and MacAuley, 1980; Kammerer, 1982; Twort *et al*. 2000; Van der Leeden *et al.,1990*; NCDENR, 2002; World Bank, 1996).

4. Virtual water content per livestock product per country

The virtual water content of different live animals has been calculated for all countries in the world. Table 4.1 presents the result of a number of selected countries. The virtual water content of some major livestock products for few selected countries are presented in Table 4.2. The countries have been selected on the basis of their relative contribution to the global virtual water trade (see Section 5). The representative virtual water content per animal category has been calculated per animal category by taking the ratio of the total weight of the different products from the animal category to the total virtual water trade per animal category considered. The representative virtual water content of different animal category came out as: Horse (12209 m^3/t), Sheep (6342 m^3/t), Goats (8500 m^3/t), Bovine (12149 m^3/t), Swine (3441 m^3/t), Dairy cow (1904 m^3/t), Layers (4606 m^3/t), Poultry (1968 m^3/t) and fowls (2432 m^3/t).

Table 4.1. Virtual water content of different live animals for a few selected countries in m^3/ton of live animal.

	Virtual water content of a live animal (m^3/t)								
	Horses	Sheep	Goats	Bovine	Swine	Dairy cow (Milk)	Layers (Eggs)	Poultry	Fowls
Australia	11707	6343	6585	11707	6117	1213	4053	2373	2373
Canada	9619	5666	5440	9619	3268	823	2314	1358	1358
China	11186	5940	10016	11186	2160	2079	8651	3111	3111
India	12729	6589	11237	12729	4175	2596	23692	8499	8499
Ireland	7575	5246	4809	7575	2012	715	1544	908	908
Italy	9581	5710	5407	9581	3459	842	2792	1637	1637
Japan	10751	5786	6105	10751	4325	1113	3488	2044	2044
Korea D P Rp	11116	5926	8096	11116	3526	1597	6874	2860	2860
Korea Rep.	13172	6735	9572	13172	6685	2171	13668	5679	5679
Netherlands	7680	5261	4823	7680	2086	730	1555	914	914
Russian Fed.	12310	6495	9055	12310	5488	1967	11312	4702	4702
USA	10056	5715	5592	10056	3371	827	2222	1304	1304

Table 4.2. Virtual water content (m^3/ton) of a few major livestock products for a few selected countries.

Products	Australia	New Zealand	USA	Ireland	Canada	Netherlands	Japan	Italy	Russian Fed.	Korea	China	India	World average*
Bovine cuts boneless, frozen	20920	17775	17972	13542	17192	13731	19212	17123	21996	23535	19989	22744	18388
Bovine, live except pure-bred breeding	11707	9945	10056	7575	9619	7680	10751	9581	12310	13172	11186	12729	9501
Bovine cuts boneless, fresh or chilled	20920	17775	17972	13542	17192	13731	19212	17123	21996	23535	19989	22744	17769
Bovine and equine leather, tanned or retanned, nes	13027	11074	11196	8445	10712	8562	11967	10669	13695	14651	12449	14160	11487
Bovine hides, whole, fresh or wet-salted	10461	8888	8987	6772	8597	6866	9607	8563	11000	11769	9996	11374	8693
Bovine cuts bone in, fresh or chilled	16735	14219	14377	10833	13753	10984	15369	13698	17596	18827	15990	18195	12362
Cheese nes	7149	11330	4881	4224	4854	4308	6563	4965	11582	12781	12240	15283	5499
Swine cuts, frozen nes	10051	7001	5547	3318	5379	3440	7112	5692	9020	10983	3561	6865	4417
Bovine leather, otherwise pre-tanned, nes	13027	11074	11196	8445	10712	8562	11967	10669	13695	14651	12449	14160	11949

Products	Australia	New Zealand	USA	Ireland	Canada	Netherlands	Japan	Italy	Russian Fed.	Korea	China	India	World average*
Eggs, bird, in shell, fresh, preserved or cooked	4053	10051	2222	1544	2314	1555	3488	2792	11312	13668	8651	23692	4752
Sausage&sim prod of meat,meat offal/blood&food prep basd on these prod	8973	7624	7708	5808	7374	5889	8240	7344	9434	10094	8574	9755	7041
Bovine carcasses and half carcasses, fresh or chilled	15898	13508	13658	10291	13065	10434	14600	13013	16716	17885	15191	17285	11618
Milk not concentrated & unsweetened exceeding 1% not exceeding 6% fat	1284	2037	876	758	871	773	1179	891	2082	2298	2201	2749	874
Swine cuts, fresh or chilled, nes	10051	7001	5547	3318	5379	3440	7112	5692	9020	10983	3561	6865	4056
Bovine meat and meat offal nes,excluding livers, prepared or preserved	9445	8025	8114	6114	7762	6199	8674	7731	9931	10625	9025	10269	8529
Hams, shoulders and cuts thereof, of swine bone in, fresh or chilled	10051	7001	5547	3318	5379	3440	7112	5692	9020	10983	3561	6865	3685
Bovine cuts bone in, frozen	16735	14219	14377	10833	13753	10984	15369	13698	17596	18827	15990	18195	13188
Milk powder not exceeding 1.5% fat	2426	3847	1654	1431	1645	1460	2226	1683	3933	4341	4157	5192	2178
Sheep, live	6343	5674	5715	5246	5666	5261	5786	5710	6495	6735	5940	6589	6082
Milk and cream powder unsweetened exceeding 1.5% fat	2426	3847	1654	1431	1645	1460	2226	1683	3933	4341	4157	5192	2283
Guts, bladders and stomachs of animals except fish whole or in pieces	8973	7624	7708	5808	7374	5889	8240	7344	9434	10094	8574	9755	7347
Bovine and equine leather, full/split grains, nes	13027	11074	11196	8445	10712	8562	11967	10669	13695	14651	12449	14160	11514
Swine, live except pure-bred breeding weighing 50 kg or more	6117	4258	3371	2012	3268	2086	4325	3459	5488	6685	2160	4175	2732

** World average for livestock products have been calculated as the ratio of total global product trade volume to the global virtual water trade volume for concerned livestock product.*

5. Global trade in virtual water related to the trade of livestock and livestock products

The global virtual water trade during the period 1995-1999 in so far related to international trade of livestock and livestock products is 245 Gm^3/yr. Products from beef cattle have the largest share in gross trade of virtual water (63%), followed by dairy cow products (12%), swine products (10%) and sheep products (4%). The trade per animal category is shown in Figure 5.1. The products having more than 1% contribution to the global gross virtual water trade in the period 1995-1999 are presented in Table 5.1.

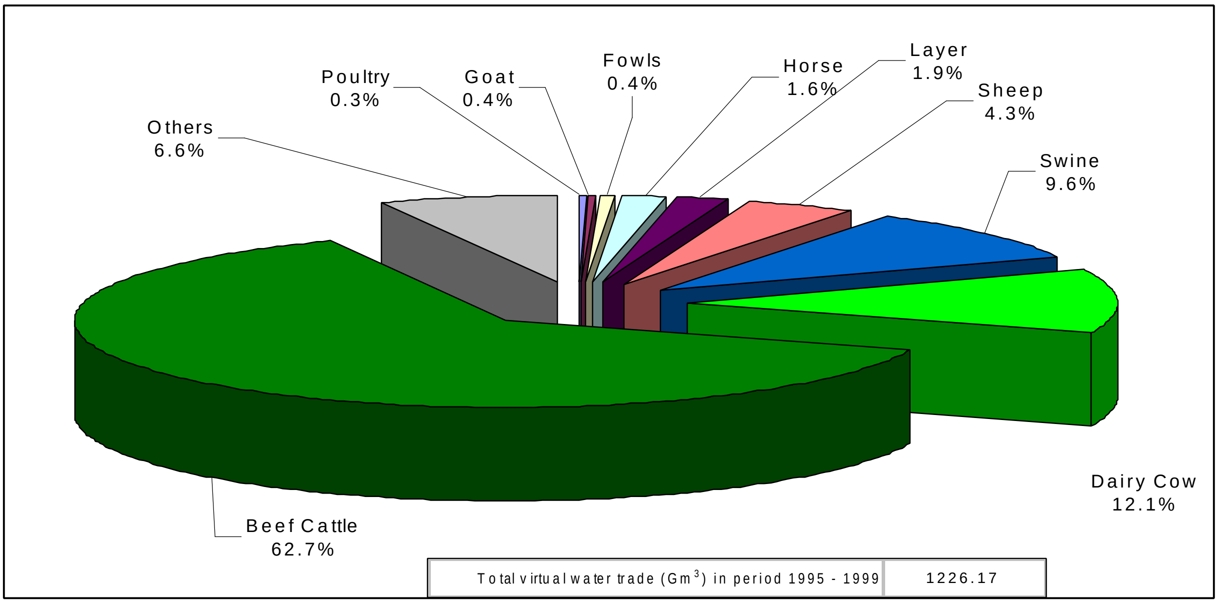

Figure 5.1. Global gross virtual water trade per animal category (1995-1999).

Table 5.1. Livestock products with >1% contribution to global gross virtual water trade (1995-1999).

Product	Gross virtual water trade (Gm^3)	Contribution to the total trade (%)
Bovine cuts boneless, frozen	199.8	16.3
Bovine, live except pure-bred breeding	100.5	8.2
Bovine cuts boneless, fresh or chilled	97.8	8.0
Bovine and equine leather, tanned or retanned, nes	86.7	7.1
Bovine hides, whole, fresh or wet-salted	68.0	5.5
Bovine cuts bone in, fresh or chilled	55.6	4.5
Cheese nes	55.2	4.5
Bovine leather, otherwise pre-tanned, nes	29.8	2.4
Sheep, live	16.5	1.3
Sheep cuts, bone in, frozen	9.9	0.8
Eggs, bird, in shell, fresh, preserved or cooked	20.9	1.7
Sausage& sim prod of meat, meat offal/blood & food prep basd on these prod	20.9	1.7
Bovine carcasses and half carcasses, fresh or chilled	19.3	1.6
Milk not concentrated & unsweetened exceeding 1% not exceeding 6% fat	19.2	1.6
Bovine meat and meat offal nes,excluding livers, prepared or preserved	17.8	1.5
Bovine cuts bone in, frozen	16.9	1.4
Milk powder not exceeding 1.5% fat	16.8	1.4
Milk and cream powder unsweetened exceeding 1.5% fat	16.4	1.3
Guts, bladders and stomachs of animals except fish whole or in pieces	13.8	1.1
Bovine and equine leather, full/split grains, nes	13.8	1.1
Sheep cuts, boneless, frozen	5.7	0.5
Swine cuts, frozen nes	30.9	2.5
Bovine edible offal, frozen nes	11.9	1.0
Remaining products	282	23.0
Global virtual water trade	**1226.1**	**100**

The top-twenties of net exporter countries and net importer countries for the period 1995-1999 are listed in Table 5.2. The table shows the ranking in *net* import or export. If we look at *gross* export of virtual water, the top-7 list of exporting countries is: USA (202 Gm^3), Australia (150 Gm^3), France (76 Gm^3), Canada (73 Gm^3), New Zealand (73 Gm^3), Germany (72 Gm^3) and the Netherlands (67 Gm^3). Though the USA is the largest gross exporter, it is at the third position in the net exporters list. The reason is that the USA is world's has largest gross importer as well. The top-7 list of gross importing countries is: USA (140 Gm^3), Italy (123 Gm^3), Japan (116 Gm^3), Germany (70 Gm^3) France (54 Gm^3) Korea Republic (50 Gm^3) and Russian Federation (50 Gm^3).

There are 29 countries having more than 1 Gm^3 export of virtual water related to trade in livestock and livestock products and 49 countries with more than 1 Gm^3 import. Only 44 countries have net export and rest of the countries in the world, which is a much larger number, have net import. This clearly shows that the market is characterised by a relatively small number of big exporters and a relatively large number of importers.

Table 5.2. Top-20 of virtual water exporters and top-20 of virtual water importers (1995-1999). Note that virtual water trade volumes refer to virtual water trade in relation to international trade of livestock and livestock products only.

Country	**Net export volume (Gm^3)**	**Rank**	**Country**	**Net import volume (Gm^3)**
Australia	146	1	Japan	112
New Zealand	71	2	Italy	93
USA	62	3	Hong Kong	46
Canada	48	4	Russian Fed	39
Argentina	33	5	Korea Rep.	35
Ireland	31	6	Taiwan	29
Denmark	28	7	Untd Kingdom	20
Netherlands	24	8	Indonesia	15
Uruguay	23	9	Mexico	14
France	22	10	Philippines	14
Belgium-Lux	16	11	Egypt	12
Brazil	15	12	Untd Arab Emirated	11
India	11	13	Portugal	11
Poland	11	14	Greece	11
Sri Lanka	10	15	Singapore	10
Austria	6	16	Saudi Arabia	9
China	5	17	Chile	8
Hungary	5	18	Lebanon	6
Nicaragua	4	19	Turkey	5
Lithuania	3	20	Israel	5

According to a recent study on virtual water trade of Japan (Oki *et al*., 2003), the total virtual water trade balance per year is 24.1 Gm^3 per year. The study is carried out only for some selected livestock products and has taken common virtual water content for each animal across different countries across the globe. This may be the reason behind conservative result of that study. Table 5.3 gives a comparison between the results of the current study and the results of Oki *et al*. (2003) for the most important exporter countries for Japan.

Table 5.3. Net virtual water import of Japan related to the trade of livestock products.

Exporting countries	Total import (Gm^3/yr)	
	Oki *et al.* (2003) (Period 1998 – 1999)	Present study (Period 1995 – 1999)
USA	9.5	10.1
Australia	5.4	7.9
Canada	1.0	0.7
Others	6.4	3.7
Grand total	22.3	22.3

The virtual water trade balances for different countries are shown in Figure 5.2, In the map, red colour is used for net import and green for net export with high in colour intensities for high volume of trade flows.

To visualise the trade flows of virtual water in more aggregated form, the world has been classified into thirteen regions: North America, Central America, South America, Eastern Europe, Western Europe, Central and South Asia, the Middle East, South-east Asia, North Africa, Central Africa, Southern Africa, the Former Soviet Union, and Oceania. The gross virtual water trade between and within regions in the period 1995-1999 is presented in Table 5.4. The net virtual water trade flows more than 10 Gm^3 are indicated with arrows in Figure 5.3.

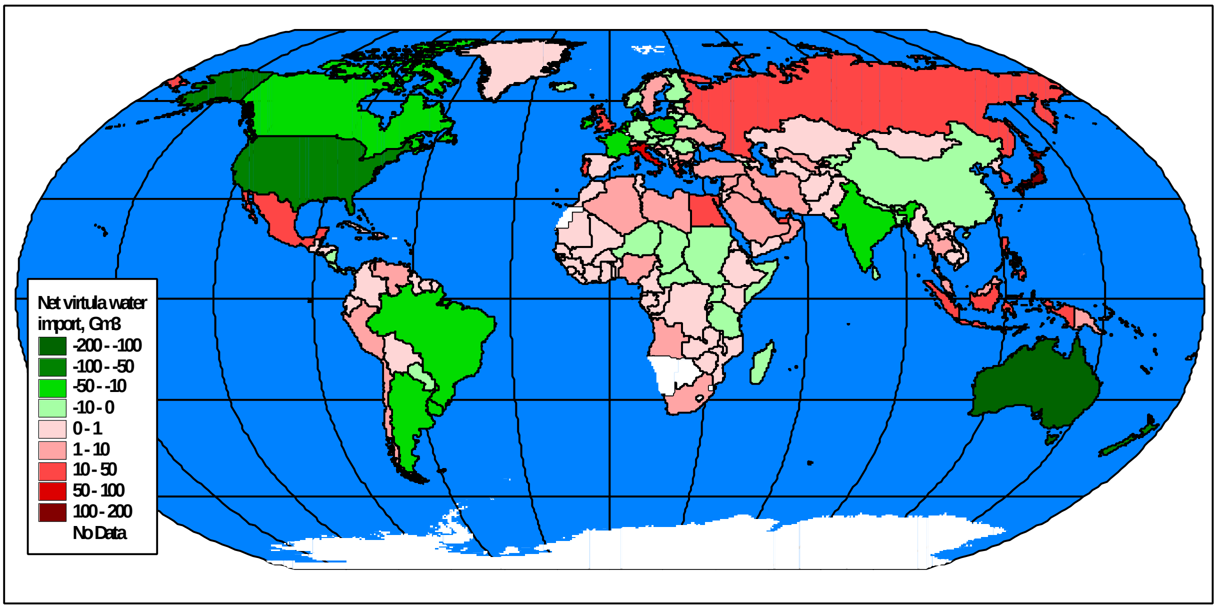

Figure 5.2. National virtual trade balances related to trade of livestock and livestock products. Period: 1995-1999. Green colour indicates net export and red colour net import)

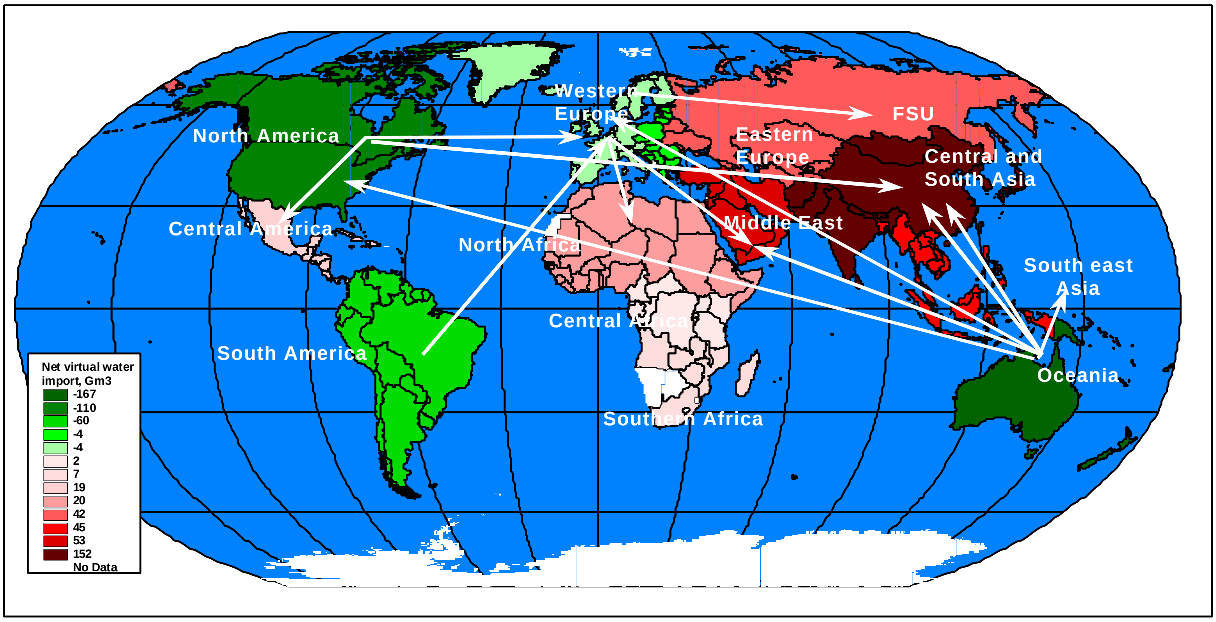

Figure 5.3. Virtual water trade balances of thirteen world regions related to the trade of livestock and livestock products. Period: 1995-1999. Green coloured regions have net virtual water export; red coloured regions have net virtual water import. The arrows show the largest net virtual water flows between regions greater than>10 Gm^3.

Table 5.4. Gross virtual water trade related to livestock trade between world regions in the period 1995-1999 (Gm3). The shaded cells refer to gross trade between countries within the regions.

Importer Exporter	Central Africa	Central America	Central and South Asia	Eastern Europe	FSU	Middle East	North Africa	North America	Oceania	South America	South East Asia	Southern Africa	Western Europe	Total gross export
Central Africa	0.037	0.001	0.143	0.000	0.000	0.024	0.003	0.001	0.186	0.000	0.001	0.001	0.128	0.49
Central America	0.000	5.250	0.628	0.004	0.017	0.011	0.000	14.718	0.294	0.521	0.006	0.001	0.742	17.33
Central and South Asia	0.148	0.050	22.431	1.410	3.868	8.951	0.052	1.675	15.890	0.193	11.489	0.674	5.968	50.37
Eastern Europe	0.002	0.107	0.516	11.427	10.742	2.624	0.556	1.007	0.085	0.087	0.453	0.043	21.494	38.13
FSU	0.000	0.000	0.326	3.083	3.014	1.173	0.000	0.164	0.025	0.010	0.008	0.000	6.357	11.15
Middle East	0.000	0.009	0.201	0.329	0.627	6.962	0.095	0.124	0.139	0.017	0.031	0.005	0.949	2.69
North Africa	0.025	0.001	0.053	0.030	0.001	2.207	3.087	0.007	0.056	0.002	0.001	0.001	0.740	3.15
North America	0.020	26.971	115.499	1.788	4.814	1.386	1.239	76.937	13.976	2.112	9.767	0.808	20.546	198.93
Oceania	0.040	4.563	68.145	2.017	2.595	16.159	5.380	55.730	10.978	2.733	28.583	3.308	20.923	214.07
South America	0.292	1.953	4.378	0.625	0.266	5.413	0.551	8.903	5.767	34.886	1.536	0.440	37.741	68.08
South East Asia	0.009	0.021	2.469	0.023	0.022	0.066	0.028	0.990	2.177	0.059	9.205	0.038	3.127	9.03
Southern Africa	0.060	0.005	0.172	0.021	0.005	0.068	0.011	0.166	0.192	0.008	0.064	0.348	0.968	1.74
Western Europe	1.489	2.237	9.615	24.910	29.804	17.990	14.758	5.616	7.828	1.912	2.486	3.656	302.999	123.46
Total gross import	2.085	35.917	202.145	34.241	52.761	56.073	22.673	89.102	46.616	7.654	54.425	8.975	119.682	738.61

Gross virtual water trade export and import of the thirteen world regions are shown in Figure 5.4. From this figure we can easily see that only four regions (Central and South Asia, North America, Oceania and Western Europe) are dominating the regional virtual water trade related to the trade of livestock and livestock products. Western Europe has large gross export, but it is not the largest net exporter as it has large gross import as well.

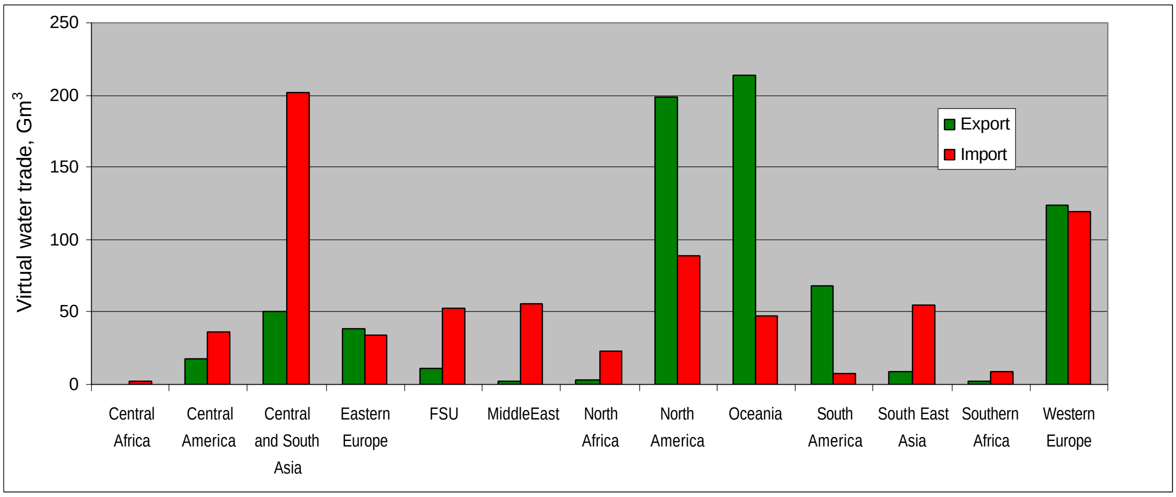

Figure 5.4. Gross virtual water import and export per region in the period 1995-1999 (Gm^3).

Regions with a significant net virtual water import are: Central and South Asia, the Middle East, Former Soviet Union, South-east Asia. Five other regions with net virtual water import, but less substantial, are North Africa, Central America, Southern Africa, Eastern Europe and Central Africa. Regions with substantial net virtual water export are: Oceania, North America, Western Europe, and South America. The thirteen world regions have been ranked based on their virtual water trade balance in Table 5.5. Oceania is by far the biggest net virtual water exporter in the world, while Central and South Asia is by far the biggest net virtual water importer. We still talk about virtual water trade in relation to trade in livestock and livestock products only!

Table 5.5. Ranking of regions in terms of their virtual water trade balance related to trade of livestock products in the period 1995-1999.

Rank	Region	Trade balance (Gm^3) = Gross import - gross export
1	Oceania	-167.45
2	North America	-109.82
3	South America	-60.42
4	Eastern Europe	-3.89
5	Western Europe	-3.78
6	Central Africa	1.60
7	Southern Africa	7.23
8	Central America	18.59
9	North Africa	19.52
10	FSU	41.61
11	South East Asia	45.40
12	Middle East	53.39
13	Central and South Asia	151.77

6. Global trade in virtual water: the total picture

The assessment of global trade of virtual water related to the international trade of crops has been carried out by Hoekstra and Hung (2002, 2003). The results show that the global trade of virtual water in relation to the trade of crop is 695 Gm^3/yr in average over the period 1995-1999. United States, Canada, Thailand, Argentina and India are the largest net exporters. Sri Lanka, Japan, Netherlands, Republic of Korea, and China are the largest net importers.

The total picture of the virtual water trade related to trade of agriculture products includes virtual water trade in relation to the international trade of crop and that related to the international trade of livestock and livestock products. The trade data related to crop are added with those related to the trade of livestock and livestock products. The combined gross virtual water trade during the period 1995-1999 was 940 Gm^3 per year (Table 6.1). One can immediately see that virtual water trade related to the trade of livestock and their product is nearly half of that related to crop trade.

Table 6.1. Total gross virtual water trade (Gm^3) related to trade of crops and the trade of livestock and livestock products during period 1995-1999.

Year	Gross virtual water trade (Gm^3)		
	Related to crop trade	Related to livestock product trade	Total
1995	559	231	790
1996	813	241	1054
1997	793	258	1051
1998	700	250	950
1999	601	246	847
Five years total	3475	1226	4701
Annual average	695	245	940

Total water use by crops production in the world is 5400 Gm^3/yr (Rockström and Gordon, 2001). The virtual water trade related to trade of crop and livestock product is about 17 % of total water used for crop production.

The gross virtual water trade related to the trade of crop, livestock and livestock products for top-12 net exporters and top-12 net importers are presented in Table 6.2.

Table 6.2. Top-12 lists of countries in terms of net virtual water import. Period: 1995-1999.

Countries with net export	Trade volume (Gm^3)			Rank	Countries with net import	Trade volume (Gm^3)		
	Export	Import	Net export			Export	Import	Net import
United States	1106.8	286.8	820	1	Sri Lanka	19	437.5	418.5
Canada	370.2	49.6	320.6	2	Japan	5.6	414.6	409
Australia	301.2	9.2	292	3	Italy	63.8	220.8	157
Argentina	271.2	11.8	259.4	4	South Korea	15.3	163.3	148
Thailand	260.9	28.5	232.3	5	Netherlands	94	217.7	123.7
India	191.8	19.5	172.3	6	Indonesia	7.3	123.5	116.2
France	211.3	100.9	110.4	7	China	74.4	171.3	96.9
Vietnam	90.9	1.7	89.2	8	Egypt	5	97	92
New Zealand	73.2	6.3	66.9	9	Spain	54.6	137.3	82.7
Brazil	194.1	134	60.1	10	Germany	120.6	186.3	65.7
Paraguay	47.1	4.1	43	11	Taiwan	0.8	65.4	64.6
Kazakhstan	39.4	0.8	38.6	12	Saudi Arabia	3.7	66.9	63.3

The relative position in this top list for different countries are more or less governed by virtual water trade related to crop. But some of the countries are now far below the list of top importer or exporter or vice versa. For example, New Zealand (4.44 Gm^3) is the virtual water importer related to trade of crop (Hoeksta and Hung, 2002), is now at 9th position in the top list of net exporter with 67 Gm^3 over the period 1995-1999. Whereas, the Netherlands balances the deficit in virtual water trade related to crop with the trade in livestock relatively from 3rd position to 5th position in the top list of importer countries. The total net virtual water trade of different countries are shown in the Fig 6.1.

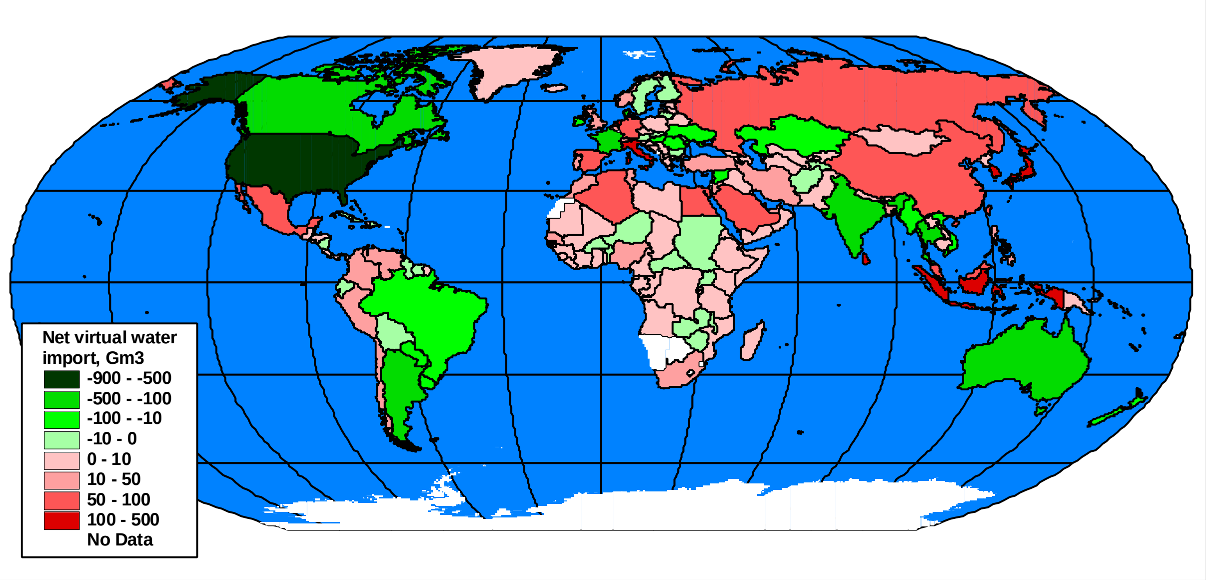

Figure 6.1. National virtual water trade balances. Period 1995-1999. Red colour is for import and green for export.

The trade volumes are aggregated over different thirteen regions and regional virtual water trades are shown in Figure 6.2. The gross virtual water trade between and within regions in the period 1995-1999 is presented in Table 6.3. The ranking of regions for virtual water trade balances of different regions related to international trade of crop, livestock and livestock products during period 1995-1999 is presented in Table 6.4. Few countries mostly dominate the regional analysis. For example, Japan (409 Gm^3) and Sri Lanka (418 Gm^3), two largest net importers, are in Central and South Asia making the whole region a net importer.

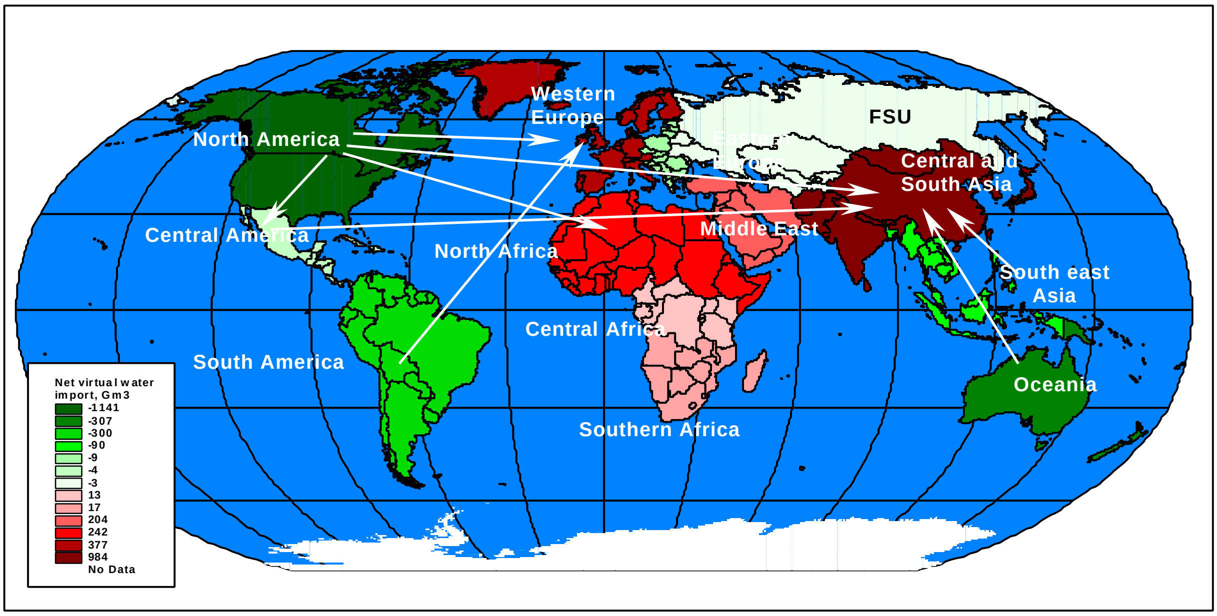

Figure 6.2. Virtual water trade balances of thirteen world regions. Period: 1995-1999

Table 6.3. Gross virtual water trade between world regions in the period 1995-1999 (Gm^3). The grey-shaded cells refer to gross trade between countries within *the regions.*

	Central Africa	Central America	Central and South Asia	Eastern Europe	FSU	Middle East	North Africa	North America	Oceania	South America	South East Asia	Southern Africa	Western Europe	Total gross export
Central Africa	1.69	0.00	0.25	0.12	0.01	0.09	0.05	0.05	0.21	0.00	0.05	0.64	2.12	3.60
Central America	0.25	9.87	125.15	0.78	4.31	0.44	1.53	55.09	0.30	2.97	0.42	0.17	15.07	206.85
Central and South Asia	3.68	0.72	122.83	4.48	13.75	30.59	13.81	5.00	16.29	1.06	76.38	10.11	23.74	199.62
Eastern Europe	0.02	0.26	3.34	31.83	15.97	12.99	8.12	1.57	0.30	0.17	1.00	0.16	58.91	103.22
FSU	0.01	0.33	8.33	16.14	51.69	30.43	3.07	1.12	0.04	0.07	0.41	0.00	41.36	101.32
Middle East	0.79	0.14	11.76	2.87	1.84	32.61	13.31	2.47	0.96	0.50	2.75	0.04	19.32	56.90
North Africa	0.16	0.15	2.51	1.17	0.22	5.95	5.83	4.19	0.06	4.61	0.16	0.43	14.53	34.14
North America	2.89	180.21	510.71	11.30	14.46	65.16	129.75	159.72	18.00	90.78	92.57	10.65	190.82	1317.31
Oceania	0.85	4.96	151.41	2.09	2.66	25.63	14.69	58.42	13.78	6.39	60.14	6.15	25.33	362.61
South America	1.92	9.11	66.67	8.46	5.12	25.67	19.18	22.27	6.11	181.62	18.04	3.19	228.95	414.91
South East Asia	1.82	2.16	229.10	2.58	6.00	25.83	31.59	13.96	4.81	3.51	96.41	11.85	14.21	347.41
Southern Africa	0.79	0.69	5.55	0.52	0.27	0.44	0.43	1.91	0.29	1.32	1.27	3.13	8.63	22.07
Western Europe	3.49	4.50	69.15	43.88	33.69	38.19	40.21	10.70	7.98	3.50	4.27	5.69	553.46	266.41
Total gross import	16.69	203.22	1183.91	94.40	98.29	261.42	275.73	176.72	55.33	114.89	257.46	49.09	642.96	3436.62

Table 6.4. Virtual water trade balance of 13 world regions in the period 1995-1999 related to trade of crop, livestock and their products (Gm^3).

World regions	Trade balance (Gm^3) = Gross import – gross export		
	Crop	Livestock and livestock products	Total
North America	-1030.8	-109.8	-1140.6
Oceania	-139.8	-167.5	-307.3
South America	-239.6	-60.4	-300.0
South East Asia	-135.3	45.4	-89.9
Eastern Europe	-4.9	-3.9	-8.8
Central America	-22.2	18.6	-3.6
FSU	-44.7	41.6	-3.0
Central Africa	11.5	1.6	13.1
Southern Africa	19.8	7.2	27.0
Middle East	151.2	53.4	204.5
North Africa	222.1	19.5	241.6
Western Europe	380.3	-3.8	376.6
Central and South Asia	832.5	151.8	984.3

The total picture of the regional analysis shows that the largest virtual water exporter is North America and the largest importer is Central and South Asia. Some regions that are net exporter in relation to crop are net importer in relation to the trade of livestock products viz. South East Asia has net export of 135 Gm^3 from crop trade during the period 1995-1999, whereas it has net export of 45 Gm^3 in the same period in the form of livestock trade. FSU and Central America, the net exporter in relation to the crop trade are nearly balance in trade if wee take into account trade related to livestock and livestock products as well.

The sum of domestic water use and net virtual water import can be seen as a kind of ‘water footprint’ of a country, on the analogy of the ‘ecological footprint’ of a nation (Hoekstra and Hung, 2002). The net virtual water import related to the trade of crop, livestock and livestock products are taken to calculate the total water footprint of a country. The indicator national water scarcity is defined as the ratio of total water use (blue water only) to water availability. The water dependency of a nation is calculated as the ratio of the net virtual water import into a country to the total national water appropriation. If net import (import – export) is positive, the country is dependent upon other countries for its domestic demand for the production of goods and services. If it is negative or zero, the country is said to be water self-sufficient. Expressing mathematically, water self-sufficiency of a nation is equal to one minus water dependency of the nation.

The water footprint per capita (m^3 per cap), water scarcity, water self-sufficiency and water dependency of a nation are calculated and presented in Table 6.5. The basic data on national water withdrawal and water availability have been taken from Raskin *et al.* (1997) and data for net virtual water import related to the trade of crop is taken from Hoekstra and Hung (2002). Note that Table 6.5 provides averages for the period 1995-1999.

Table 6.5. Water footprints, water scarcity, water self-sufficiency and water dependency of nations in an average year period of 1995-1999.

Country	Population, Average over 1997 - 2001	Water withdrawal (10^6 m^3/yr)	Water availability[1] (106 m^3/yr)	Net virtual water import (10^6 m^3/yr)		Water footprint (m^3 /cap/yr)	Water scarcity (%)	Water self-sufficiency (%)	Water dependency (%)
				Crop	Livestock				
Afghanistan	25765766	35704	50000	-229.0	3.6	1377	71.4	100.0	0.0
Albania	3387574	356	21300	263.2	85.0	208	1.7	57.5	42.5
Algeria	29959010	5042	14300	9803.7	678.3	518	35.3	34.0	66.0
Andorra	62923			2.2	85.9	1401			
Angola	67000	628	184000	168.4	240.6	15477	0.3	78.9	21.1
Anguilla	12771448			1.3	0.1	0			
Antigua Barb	67413			8.8	9.4	269			
Argentina	36577450	35812	994000	-45268.4	-6603.9		3.6	100.0	0.0
Armenia	3798845	4109	13300	310.6	-0.7	1163	30.9	93.0	7.0
Aruba	97200			6.9	22.9	307			
Australia	18963804	27312	343000	-29119.3	-29273.3		8.0	100.0	0.0
Austria	8095446	2424	90300	304.9	-1190.5	190	2.7	100.0	0.0
Azerbaijan	7979460	17061	33000	974.4	104.5	2273	51.7	94.6	5.4
Bahamas	298331			-50.3	84.6	115			
Bahrain	666956	334	290	137.1	290.3	1142	115.2	70.9	29.1
Bangladesh	128837760	26467	2357000	5742.0	-97.8	249	1.1	82.2	17.8
Barbados	266262			102.2	72.4	656			
Belarus	10039496	2979	73800	1220.9	-325.7	386	4.0	70.9	29.1
Belgium-Lux	10227060	9237	12500	11915.4	-3261.1	1749	73.9	43.7	56.3
Belize	232143			-85.3	12.8				
Benin	6112575	154	25800	-605.3	38.8		0.6	100.0	0.0
Bermuda	63000			134.6	34.5	2684			
Bhutan	782229	23	95000	26.5	0.1	63	0.02	46.5	53.5
Bolivia	8139894	1557	300000	-1057.3	96.5	73	0.5	100.0	0.0
Bosnia Herzg	3865576	1354	265000	174.2	609.5	553	0.5	88.6	11.4
Brazil	168220660	46856	6950000	-9000.2	-3015.0	207	0.7	100.0	0.0
Brunei Dar.	329686			323.8	130.8	1379			
Bulgaria	8213543	13576	205000	-471.4	416.2	1646	6.6	100.0	0.0
Burkina Faso	11005226	412	17500	-904.7	8.3		2.4	100.0	0.0
Burundi	6677800	127	3600	3.4	1.2	20	3.5	97.4	2.6
Cambodia	11755836	660	498100	102.4	27.9	67	0.1	86.6	13.4
Cameroon	14557762	500	268000	-12.6	14.4	34	0.2	102.6	-2.6
Canada	30498614	47246	2901000	-54494.0	-9628.4		1.6	100.0	0.0
Cape Verde		30	300000		14.8		0.01		
Cayman Islds	35000			92.5	28.3	3452			
Cent.Af.Rep	3657263	85	141000	-1.1	0.9	23	0.1	100.0	0.0
Chad	7492965	218	43000	1.4	0.9	29	0.5	99.4	0.6
Chile	15013962	23203	468000	2051.4	1553.1	1786	5.0	91.9	8.1
China	1252042000	504315	2800000	20435.6	-1005.8	418	18.0	96.1	3.9

Country	Population, Average over 1997 - 2001	Water withdrawal (10^6 m^3/yr)	Water availability[1] (106 m^3/yr)	Net virtual water import (10^6 m^3/yr)		Water footprint (m^3/cap/yr)	Water scarcity (%)	Water self-sufficiency (%)	Water dependency (%)
				Crop	Livestock				
Christmas Is				0.0	0.7				
Cocos Islnds				2.1	0.0				
Colombia	41543956	6031	1070000	6670.2	32.4	307	0.6	47.5	52.5
Comoros	544534	13	1020	39.3	46.0	180	1.3	24.9	75.1
Congo	49563472	51	832000	86.6	96.2	5	0.0	37.1	62.9
Congo, D.R.	2934512			314.9	91.3	138			
Cook Islands				0.8	5.8				
Costa Rica	3731672	1464	95000	1257.7	-432.3	613	1.5	53.8	46.2
Cote d'Ivoire	15580058	941	77700	690.0	80.5	110	1.2	57.7	42.3
Croatia	4395695	1760	265000	223.9	594.2	587	0.7	88.7	11.3
Cuba	11150144	9585	34500	-221.5	185.1	856	27.8	100.0	0.0
Cyprus	752931			1064.8	-5.1	1407			
Czech Rep	10283004	2727	58200	484.5	-422.2	271	4.7	84.9	15.1
Denmark	5318089	1210	13000	-461.0	-5646.6		9.3	100.0	0.0
Djibouti	620352	11	2300	109.3	8.2	207	0.5	9.1	90.9
Dominica	73040			-618.2	4.6				
Dominican Rp	8237523	3483	20000	-1932.1	554.6	256	17.4	100.0	0.0
Ecuador	12409904	6677	314000	-590.2	6.5	491	2.1	100.0	0.0
Egypt	62782964	55432	68500	16035.5	2373.8	1176	80.9	77.6	22.4
El Salvador	6155042	1084	19000	1047.7	408.9	413	5.7	50.9	49.1
Eq.Guinea	445088			1.3	8.8	23			
Eritrea	3988805	240	8800	74.6	1.1	79	2.7	76.3	23.7
Estonia	1388705	3220	17600	530.6	-110.9	2621	18.3	85.9	14.1
Ethiopia	62782412	2156	110000	326.4	1.6	40	2.0	86.8	13.2
Faeroe Islds	45000			1.2	20.0	473			
Falkland Isl				0.7	1.7				
Fiji	802087	33	28600	174.6	117.5	405	0.1	15.9	84.1
Finland	5164368	2243	113000	-172.9	-294.1	344	2.0	100.0	0.0
Fr.Guiana				0.4	8.2				
Fr.Polynesia	231362			13.6	138.9	659			
Fr.So.Ant.Tr				0.0	0.6				
France	58656600	38570	198000	-17675.1	-4400.6	281	19.5	100.0	0.0
Gabon	1198661	78	164000	100.0	130.7	258	0.0	43.8	56.2
Gambia	1263370	36	8000	155.1	6.7	157	0.5	18.8	81.2
Georgia	5188007	4054	65200	205.4	65.9	834	6.2	95.2	4.8
Germany	82109980	47303	171000	13589.1	-459.0	736	27.7	77.7	22.3
Ghana	18875980	325	53200	453.8	94.3	46	0.6	41.7	58.3
Gibraltar				10.9	19.6				
Greece	10537058	7109	58700	-1966.6	2163.9	693	12.1	138.2	-38.2
Greenland	56100			1.2	23.4	440			
Grenada	97140			30.5	11.6	433			

Country	Population, Average over 1997 - 2001	Water withdrawal (10^6 m^3/yr)	Water availability[1] (106 m^3/yr)	Net virtual water import (10^6 m^3/yr)		Water footprint (m^3 /cap/yr)	Water scarcity (%)	Water self-sufficiency (%)	Water dependency (%)
				Crop	Livestock				
Guadeloupe	151782			3.6	21.7	167			
Guatemala	11095762	1501	116000	-14341.5	105.2		1.3	100.0	0.0
Guinea	7250572			41.2	17.7	8			
Guinea Bissau	1174665	22	27000	2.9	2.9	24	0.1	88.3	11.7
Guyana	757015	1501	241000	-158.7	23.4	1804	0.6	100.0	0.0
Haiti	7803032	47	11000	389.0	45.6	62	0.4	10.8	89.2
Honduras	6257825	1656	63400	467.4	79.4	352	2.6	78.0	22.0
Hong Kong				2868.3	9170.5				
Hungary	10221682	6678	120000	-3954.0	-907.3	178	5.6	100.0	0.0
Iceland	277700	167	168000	63.2	-27.3	731	0.1	72.5	27.5
India	997775760	607227	2085000	-32199.3	-2251.6	574	29.1	100.0	0.0
Indonesia	207029780	83061	2530000	20227.0	2917.6	513	3.3	80.4	19.6
Iran	62762116	85608	117500	5819.7	776.4	1469	72.9	93.6	6.4
Iraq	22797032	52259	109200	1097.4	537.7	2364	47.9	97.9	2.1
Ireland	3752276	808	50000	743.9	-6261.0		1.6	100.0	0.0
Israel	6100032	2277	2200	4598.2	983.9	1288	103.5	33.1	66.9
Italy	57627528	56362	167000	12863.7	18538.9	1523	33.7	81.4	18.6
Jamaica	2604246	414	8300	255.5	198.2	333	5.0	61.8	38.2
Japan	126624200	91945	547000	59443.6	22316.6	1372	16.8	60.7	39.3
Jordan	4742815	907	1700	4481.0	56.5	1148	53.4	16.8	83.2
Kazakstan		44138	169400	-7834.2	119.6		26.1		
Kenya	29402552	2454	30200	800.5	9.5	111	8.1	75.4	24.6
Kiribati	88274			0.3	4.8	57			
Korea D P Rp	22141004	16407	67000	640.8	43.1	772	24.5	96.2	3.8
Korea Rep.	46839720	29558	66100	22513.6	7092.8	1263	44.7	56.8	43.2
Kuwait	1925635	472	758000	497.7	816.3	928	0.1	48.7	51.3
Kyrgyzstan	4844973	12953	61700	47.3	-28.9	2677	21.0	99.6	0.4
Lao	5159165	1260	270000	92.5	9.4	264	0.5	93.2	6.8
Latvia	2408205	673	34000	248.0	38.4	398	2.0	73.1	26.9
Lebanon	4267969	1178	5600	746.8	1157.2	722	21.0	61.2	38.8
Liberia	3046804	168	232000	65.7	16.8	82	0.1	71.9	28.1
Libya	5176657	4751	600000	743.7	595.0	1176	0.8	86.5	13.5
Lithuania	3531820	4416	24200	116.5	-690.8	1088	18.2	100.0	0.0
Macau	431878			96.5	101.6	459			
Macedonia	2020714	847	265000	51.1	234.3	560	0.3	94.3	5.7
Madagascar	15057966	23135	337000	188.3	-44.2	1546	6.9	99.2	0.8
Malawi	10096722	971	18700	-760.8	6.6	21	5.2	100.0	0.0
Malaysia	22724518	13058	456000	10252.4	778.3	1060	2.9	56.0	44.0
Maldives	269312			11.6	21.9	124			
Mali	10588286	1746	100000	65.0	21.2	173	1.7	96.4	3.6
Malta	387600			271.7	158.3	1110			

Country	Population, Average over 1997 - 2001	Water withdrawal (10^6 m^3/yr)	Water availability[1] (106 m^3/yr)	Net virtual water import (10^6 m^3/yr)		Water footprint (m^3 /cap/yr)	Water scarcity (%)	Water self-sufficiency (%)	Water dependency (%)
				Crop	Livestock				
Marshall Is.	51700			2.1	5.3	143			
Martinique				-9.9	23.2				
Mauritania	2579964	1851	11400	375.1	14.4	868	16.2	83.1	16.9
Mauritius	1173176	390	2200	289.7	187.9	740	17.7	57.4	42.6
Mexico	96615488	84209	357400	8986.7	2854.9	994	23.6	90.4	9.6
Micron, F. State				9.4	8.9				
Moldova Rep.	4291104	3787	13700	-372.7	-146.2	762	27.6	100.0	0.0
Mongolia	2377183	657	24600	14.5	7.7	286	2.7	97.8	2.2
Montserrat				-40.1	0.1				
Morocco	28240226	11540	30000	5530.4	194.4	611	38.5	67.6	32.4
Mozambique	17331232	655	216000	251.9	39.3	55	0.3	72.2	27.8
Myanmar	47134402	4694	1082000	-3480.2	64.5	27	0.4	100.0	0.0
N.Caledonia	208946			19.7	35.3	264			
N.Mariana	72000			5.1	3.2	114			
Nauru				0.2	6.0				
Nepal	22507210	3284	170000	28.6	-0.2	147	1.9	99.1	0.9
Neth. Antilles	213148			52.0	122.8	820			
Netherlands	15812200	8039	90000	29539.7	-4817.7	2072	8.9	21.4	78.6
New Zealand	3808760	1992	327000	887.5	-14276.2		0.6	100.0	0.0
Nicaragua	4940828	1688	175000	250.5	-756.8	239	1.0	100.0	0.0
Niger	10478080	628	32500	201.6	-537.2	28	1.9	100.0	0.0
Nigeria	123837060	4648	280000	4862.0	527.6	81	1.7	48.9	51.1
Norfolk Isld				0.7	1.2				
Norway	4461300	2077	392000	2203.6	-193.7	916	0.5	48.5	51.5
Oman	2350640	524	2103	1108.5	420.1	873	24.9	32.1	67.9
Pakistan	134871900	278844	468000	-9.8	92.0	2068	59.6	100.0	0.0
Palau	19100			4.0	2.5	342			
Panama	2810118	1975	144000	208.7	-104.0	740	1.4	90.4	9.6
Papua N.Guin	5006703	120	801000	28.5	471.5	124	0.01	80.8	19.2
Paraguay	5358929	541	314000	-8425.1	-180.4		0.2	100.0	0.0
Peru	25230198	18726	40000	5422.8	367.8	972	46.8	77.5	22.5
Philippines	74178100	49035	323000	964.7	2804.7	712	15.2	98.1	1.9
Pitcairn				0.0	0.1				
Poland	38654642	12349	56200	3757.7	-2107.5	362	22.0	76.7	23.3
Portugal	10028200	7257	69600	6228.1	2178.0	1562	10.4	53.8	46.2
Qatar	563710	226	195	59.3	245.5	942	115.9	79.2	20.8
Reunion				62.4	21.0				
Romania	22469358	25173	208000	-1823.5	-376.9	1022	12.1	100.0	0.0
Russian Fed	146180880	116422	4498000	2454.9	7835.9	867	2.6	97.9	2.1
Rwanda	8304804	809	6300	92.9	5.3	109	12.8	89.7	10.3
South Africa	42043988	14890	50000	4369.3	978.3	481	29.8	77.3	22.7

Country	Population, Average over 1997 - 2001	Water withdrawal (10^6 m^3/yr)	Water availability[1] (106 m^3/yr)	Net virtual water import (10^6 m^3/yr)		Water footprint (m^3/cap/yr)	Water scarcity (%)	Water self-sufficiency (%)	Water dependency (%)
				Crop	Livestock				
S.Vincent-Gr	114120			56.3	7.0	554			
Samoa	2851665			-0.5	39.2	14			
Sao Tome Prn	144854			3.4	2.0	37			
Saudi Arabia	20239432	5092	8760	10878.1	1775.0	877	58.1	31.9	68.1
Senegal	9279048	1702	39400	2636.8	1.9	468	4.3	39.2	60.8
Seychelles	79969			27.8	12.5	504			
Sierra Leone	4932139	445	160000	82.6	4.4	108	0.3	84.3	15.7
Singapore	3957913	211	600	3404.1	2055.9	1433	35.2	5.8	94.2
Slovakia	5395677	1818	30800	-590.8	-76.5	213	5.9	100.0	0.0
Slovenia	1986239	762	265000	1041.1	-226.4	794	0.3	42.3	57.7
Solomon Isls	416546			-1.3	3.5	5			
Somalia	8480576	914	13500	277.1	0.8	141	6.8	76.7	23.3
Spain	39415552	30968	111300	16503.6	50.3	1206	27.8	65.2	34.8
Sri Lanka	19075498	10410	43200	85693.3	-1985.2	4934	24.1	10.8	89.2
St.Helena				1.5	0.6				
St.Kitts Nev	40920			0.9	4.0	120			
St.Lucia	153891			-1041.0	22.9				
St.Pier.Miqu				0.1	1.9				
Sudan	30534126	17800	154000	-1151.1	-411.4	532	11.6	100.0	0.0
Suriname	415105	518	200000	-86.9	14.9	1074	0.3	100.0	0.0
Sweden	8864128	2990	180000	-839.9	560.7	306	1.7	100.0	0.0
Switzerland-Liecht	7145332	1146	50000	1936.5	209.4	461	2.3	37.2	62.8
Syria	15798242	10907	53700	-4378.6	213.5	427	20.3	100.0	0.0
Taiwan				7032.4	5883.8				
Tajikistan	6138744	14950	101300	-37.1	3.2	2430	14.8	100.0	0.0
Tanzania	32902714	1193	89000	928.1	-45.2	63	1.3	56.2	43.8
Thailand	60275202	35042	179000	-46665.4	201.6		19.6	100.0	0.0
Togo	4392474	115	12000	636.8	2.4	172	1.0	15.3	84.7
Tonga	99424			3.7	36.0	400			
Trinidad Tobago	1293248	163	5100	589.0	126.2	679	3.2	21.7	78.3
Tunisia	9448461	3391	9000	3867.4	146.9	784	37.7	46.7	53.3
Turkey	64341266	36237	193100	2053.1	1055.0	612	18.8	94.6	5.4
Turkmenistan	5057637	26186	72000	56.9	80.9	5205	36.4	99.8	0.2
Turks Ca.Isl				0.2	2.2				
Tuvalu				0.0	0.3				
Uganda	21616208	217	66000	-86.0	-53.9	4	0.3	100.0	0.0
Ukraine	49904874	34623	231000	-6363.8	307.5	572	15.0	100.0	0.0
Untd Arab Emirates	2800073	657	797	1691.2	2217.5	1631	82.4	28.0	72.0
United Kingdom	59481556	11929	71000	-970.4	3951.4	251	16.8	108.9	-8.9
Uruguay	3312629	4325	124000	-2401.5	-4647.8		3.5	100.0	0.0
USA	278035840	492259	2478000	-151660.0	-12338.1	1181	19.9	100.0	0.0

Country	Population, Average over 1997 - 2001	Water withdrawal (10^6 m^3/yr)	Water availability[1] (106 m^3/yr)	Net virtual water import (10^6 m^3/yr)		Water footprint (m^3 /cap/yr)	Water scarcity (%)	Water self-sufficiency (%)	Water dependency (%)
				Crop	Livestock				
Uzbekistan	24394002	91842	129600	409.0	306.7	3794	70.9	99.6	0.4
Vanuatu	191298			0.1	1.6	9			
Venezuela	23705676	4446	1317000	4925.6	257.2	406	0.3	47.4	52.6
Viet Nam	77508750	30851	376000	-18031.9	186.5	168	8.2	100.0	0.0
Wallis Fut.I	119622			-0.3	4.5	36			
Yemen	17056736	3397	4902	1437.4	132.1	291	69.3	70.3	29.7
Yugoslavia		4248	265000	-135.6	3.5		1.6		
Zambia	9872326	1759	116000	-98.1	2.4	168	1.5	100.0	0.0
Zimbabwe	12382668	1527	20000	-517.5	14.5	83	7.6	100.0	0.0
Areas not else specified				-7687.6	1253.3				
Total	5910605825	3696312	50547567	0	0				

Note: Empty field denotes cases where data are not readily available.

7. Conclusion

Inclusion of virtual water trade related to the livestock and livestock products into the virtual water trade flows related to cop gives a more complete picture. Proper accounting of all the virtual water trade flows should also include trade of processed crops and other industrial products. Though the bulk of food trade is in the form of trade of cereals, the virtual water trade related to the trade of livestock and livestock products is quite significant (nearly half of total volume of virtual water trade related to crop trade). The reason being that the virtual water content of livestock products are very high compared to the virtual water content of cereal crops. Change in dietary habit of the people can reasonably intensify or nullify the virtual trade imbalances. For example, if Chinese people change their dietary habits to that of an average American people, the virtual water trade balance of Central and South Asia region, which is already a net exporter of virtual water, may escalate severely.

When undertaking this study it soon became apparent that data weakness posed a serious constraint to such effort which may be the reason no such quantification have been attempted thus far. Missing data have to be substituted by assumptions and best estimates, all of which certainly leaves room for future improvements. It also points to a general lack of quantitative information on livestock sector, part of which can be explained by the complexity of the subject.

As this is only one step forward to define a logical methodology to calculate the virtual water trade flows in relation to the international trade of livestock products, refinement of the method with more reliable data collection is necessary before quantifying the national virtual water trade.

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4

Value of virtual water in food: Principles and virtues

D. Renault

Abstract

The value of virtual water of a food product is the amount of water per unit of food that is or that would be consumed during its production process. Five principles for assessing the value of virtual water are proposed. The first one considers common standard values per food product; which is appropriate for global studies on trade. The second one considers the marginal water requirements for an alternative production close to the consumption site. The third one introduces the nutritional equivalence between food products. The fourth one focuses on the substitution (or reallocation) to transform virtual water imports into real water savings. The fifth underlines the need for historical studies to account for gain of productivity and deflated values of virtual water.

Application of these principles illustrates some important features of virtual water. Virtual water trade is shared evenly between energetic products, fat products and protein products. Virtual water trade not only generates water savings for importing countries, but also global real water savings due to the differential in water productivity. Food storage also generates real water savings in time. The value of virtual water in sea products is globally significant, accounting for 8% of the total. Impacts of diet changes on water requirements for food are significant but the gain in water productivity in food production is more influent. Assuming that the gain in water productivity reaches 50% of yield growth, we estimate that in the European Union, water requirements for food per capita and per day have declined in real value from 5400 litres in 1961 down to 3600 litres in 2000. This conservative assumption on water productivity shows that at least 1800 litres per day per capita has been saved since 1961, thanks to the agricultural productivity.

1. Introduction

By definition virtual water is the water embedded in a product, i.e. the water consumed during its process of production. This concept emerged in the 1990s and receives more and more attention from people concerned with water management and in particular with water related to food production. Increasing intersectoral competition for water, the need to feed an ever growing population and increased water scarcity in many regions of the world, are some important reasons to look at the way water is managed on our planet, and on how human needs are considered. The water requirements for food are by far the highest: it takes 2 to 4 litres per day to satisfy the biological needs (drinking water) of a human being and about 1000 times as much to produce the food. This is why the concept of virtual water is so important when discussing food production and consumption. In simple words, a country that imports 1 million ton of wheat is importing, and therefore enlarging its water resource by, 1 billion m^3 of water.

The importance of virtual water at global level is likely to dramatically increase as projections show that food trade will increase rapidly: doubling for cereals and tripling for meat between 1993 and 2020 (Rosegrant and Ringler, 1999). Therefore the transfer of virtual water embedded in the food that is traded is becoming an important component of water management on global as well as regional level, particularly in the regions where water is scarce.

One of the fundamentals of management is the ability to measure or evaluate fluxes and volumes of the considered good, and virtual water is no exception. Its value is generally expressed per volume (m^3) which results from multiplying the quantity of product (kg) by the unit value per product, expressed as volume of water per kg of product (m^3/kg). As we do for real water, we have to have a common understanding of the values of virtual water. We have to have standardised measurement tools and methodologies to assess these values.

Still at its infant stage, virtual water has had its pros and cons, its virtual supporters and its real sceptics and vice versa. The question of its utility, and of the domains it should focus upon, are still to be answered, although preliminary studies show that improving information on virtual water is likely to put pertinent lights on the water management debate. Another important point related to production and trade, is the fact that “water” is not the only facet of the decision process. The issue of comparative advantage which is central here implies considering land, jobs, rural development, access to markets (Wichelns, 2001). It is clear that looking at water in food trade is not enough but at least, it should be well understood, and this is one purpose of current works on virtual water.

This paper aims to specifically investigate the issue of the *value of virtual water.* How can Virtual Water Value (VWV) be defined and practically assessed? This will be done by considering two points of view:

- The global point of view on food production, trade and consumption.
- The point of view of a decision maker in position to decide on food import/export, agricultural policy and natural resources management.

The paper focuses on concepts and principles in assessing the value of virtual water, and on some virtues of virtual water.

2. Visions and issues on virtual water

2.1. The supply driven vision: virtual water in food production and trade

The general and common concept of virtual water is applied for expressing various visions or perspectives on virtual water:

- *The strategic vision for food security***:** a country uses the international markets for part of its food supply in order to relieve the pressure on natural resources and in particular on water, that otherwise a self-sufficiency policy would create. This is especially important for low endowed countries, and this explains also why the first studies on virtual water have focussed on arid countries in the Middle East (Allan, 1999; Wichelns, 2001).
- *The liberal vision*: virtual water through food imports is seen as a means to open the national water market and in ensuring that water will be channelled to its more profitable use (Allan, 1999; WWC, 1998).
- *The ecological vision*: virtual water is meant to help implementing a softer approach of natural resources management, and redirect production to areas where the natural conditions are best to match efficiency as well as sustainability (Turton, 2000).
- *The solidarity vision:* it recognises that decisions about agricultural production in areas producing surplus of food, may have real impacts on the pressure exercised on water resources in poorly endowed countries and areas. This solidarity vision makes sense in particular at regional level as illustrated by some of the solutions contemplated for solving current food crisis in the SADC region (Meissner, 2003).

These four previous visions are all based on *the quest for optimal production sites* (comparative advantage) to satisfy food needs with the minimum pressure on the environment. They are basically *supply driven visions***,** which focus on *fluxes of food and virtual water* from production sites to consumption areas. This vision for water flows is very well portrayed through the idea that a second virtual Nile river is flowing towards the Middle East and North Africa (MENA) region through food imports (Allan, 1998).

2.2. The demand driven vision: virtual water in food consumption

Another vision on virtual water brought by Renault and Wallender (1999) is more demand driven: *the consumption vision.* This vision considers that the amount of water required for food production is not only driven by population but also by food habits (diets) and therefore the debate on “water for food” should be also placed at consumption level. For instance a survival diet would require 1 m^3 of water per day and per capita whereas a diet mostly made with animal product needs some 10 m^3 per day and capita. More common diets are ranking from about 2.5 m^3/capita/day for low animal product intake, e.g. in North Africa, to 5 m^3/capita/day for high animal product intake such as in Europe or in the USA.

It can be shown that changes in food habits can have a real impact on water requirements for food. As we do for other uses of water, we have to tackle water for food from both sides: the supply and the demand. In many wealthy countries the demand side contains a water-field that can be tapped to save water uses and narrow the gap between the demand and supply of water.

2.2.1 Food storage as reservoir of virtual water

The issue of optimal production is not only a problem of location of agricultural production sites but it is also time related, as it has to do with performance of agricultural seasons. Except for irrigated agriculture, agricultural performance is highly dependent on variable climatic conditions. Thus in many rainfed farming areas we have the “good years” and the “bad years”. Food storage is then used to smooth the variation of the production: storing during the good year and supply during the bad ones. This constitutes a carry over of food and virtual water from the wet years to the dry ones. This dynamic vision must also be included in the conceptual approach and in the debate on virtual water.

Food storage can be expressed into virtual water as already done for food trade. The stocks of grains worldwide represent a virtual reservoir of 500 billion m^3 of water (500 km^3). This value rises up to 830 billions m^3 when sugar, meat and oil are added. This latter value represents 14% of the real capacity of water in the existing reservoirs, i.e. 6000 billion m^3 (Shiklomanov, 2000). Furthermore if living cattle and sheep are accounted for, the total virtual water storage jumps to 4 600 billion m^3 of water (77% of the real storage value).

2.2.2 The passage from real to virtual water: transfer from production to consumption

To produce food, real water is consumed by evapotranspiration on the production site. Thus every food product can be linked to a ratio of water consumed per kg, which varies in space and in time according to the local productivity and local conditions of water supply in green water (rainfall) and in blue water (irrigation). Once the product leaves the production site (farm gate) for the consumption market, water abandons its real and tangible status to become virtual.

In the consumption domain, the value of virtual water is not strictly connected to the real production conditions and has more to do with a virtual production site and growing period closer in space and time. For instance for a nation importing cereals, the value of virtual water embedded in the imports is not the real value consumed at production site, but the value that the country would have consumed if it had to produce the food itself (value on a virtual production site). A similar reasoning applies for food transfer in time. The value of virtual water embedded in the amount of food coming from internal storage is not the value recorded during the real production period but the value that would have been consumed to produce the same amount the same year of the consumption period.

Virtual water has often been associated with trade, but it is not the process of crossing a boundary that changes the nature of water from real to virtual. This is the very passage (transfer in space and in time) from the production domain to the consumption domain, which transforms real into virtual water. For the consumer, water embedded in the food he is swallowing is always virtual.

2.2.3 The virtual water value: water evapotranspired at field level

Crop water production is governed only by transpiration. However since it is difficult to separate transpiration from evaporation from the soil surface between the plants (which does not contribute directly to crop production), defining crop water consumption in terms of evapotranspiration rather than transpiration makes practical sense at field level. Under rainfed agriculture water consumed is only green water, while for irrigated agriculture water consumption consists of green water (rainfall) and blue water (irrigation). When studying irrigated agriculture in saline areas, the leaching requirement, i.e. the amount of water that needs to percolate to maintain root zone salinity at a satisfactory level, should also be included together with evapotranspiration as the amount of water consumed (depleted) during plant growth.

Furthermore, with irrigation supply the real water consumption must account for the irrigation application and conveyance efficiencies. However, efficiencies are very much site and system specific, as seepage and deep percolation water losses are very much variable depending on techniques in use, the skill of users and the re-use of water at basin level. When losses generated in the transport and the application of irrigation water are no longer of use, then efficiency should be accounted for and real water consumption should include both ET and water losses. The issue of water productivity and water use efficiency, however, is a topic in itself.

At this stage we purposely put aside considerations on efficiency and additional water requirements (leaching) and keep the water consumption as the fraction of water evapotranspired (green +blue). The virtual water value is then defined as the quantity of water evapotranspired at field level (ET_a or SET_a) to the yield (increment or total yield). It is expressed in m^3 of water per kg of crop.

$$VWV = \frac{ET_{\mathrm{a}}\ (\mathrm{m}^3)}{Yield\ (kg)} \tag{1}$$

2.2.4 The concept of marginal virtual production site

How much water is saved when you import cereals? It is advocated here that the value of water saved has much to do with the inverse of the marginal water productivity on the consumption site, i.e. where the decision for importing is made, rather than with the water quantity really consumed on the production site.

In the first studies and discussions on virtual water and on water productivity for food, figures like 1 kg/m^3 of water for cereals have been abundantly used. Various estimations of virtual water trade are based on this unit value. This kind of worldwide reference can be used, provided that we are dealing with global trade. However, once we focus and desegregate the approach at regional, country or state levels, this type of reference might be misleading (Earle, 2001). This is the big question of average versus marginal, which is of great importance in this case because the general idea of virtual water lies on comparative advantages of different production sites (Renault and Wallender, 2000). Decisions are based and/or impact on the fringes of the resources mobilised for production (land, water, economy, etc…). Therefore the marginal approach is usually more relevant when addressing the decision making process.

2.2.5 What is the virtual water value of a sea fish?

The above definition of VWV does not allow estimation of the value of a food product that does not consume water in its production process. For example, how should the virtual water value of sea products be estimated? A response to this question is proposed in the following.

3. Principles in assessing virtual water values

Five principles are suggested for the assessment of virtual water values. The first two principles deal with the reference in computing the virtual water value. The first considers common values, as a sort of standard values, based on actual water consumption recorded on selected real production sites. The second principle considers the marginal water consumption of the location where the decision of producing or importing is made. Depending on the nature of the study on virtual water, one has to decide which of these two principles suits best the objectives. The third principle is on nutritional equivalence, which provides a means to compare food products. The fourth principle is on substitution or finding an alternative water consumption, which bounds the scope of water saving linked to virtual water. The fifth principle specifies that, thanks to water productivity gains, virtual water values are deflated at a significant pace and this principle must be considered when looking at past or future evolution of virtual water.

3.1. First principle: The principle of common values

For global analysis on virtual water and to allow comparison between virtual water fluxes there is without doubt a need to use the same common values of virtual water as standards. The real water consumed at some reference production sites can be used as reference values of virtual water.

Questions remain though on how to assign these standards, with what type of productivity and where should it be measured. It seems that three options can be considered:

- the average world wide water productivity for each product;
- the productivity recorded in the main exporting and/or producing country of each product;
- the highest national productivity recorded for each product.

As the virtual water discussion is about opportunity with regard to production sites, it would seem logical that those countries or states with the highest performing agricultural production sites should be selected to set the standards.

Figure 3.1. displays virtual water values of various agricultural products in 1990, with reference mainly to Californian production sites, except for a limited number of crops that are not produced in California (Renault

and Wallender, 2000). Here, values of virtual water have been estimated considering for each product either option b or c.

3.2. Second principle: The principle of the marginal gain in water productivity

For decision-makers in charge of water and agriculture policies, the value of virtual water that must be considered cannot be a standard value registered in a remote production site, but has to be related to the local alternatives. Water saved from internal water resources when imports of goods are increased, is the quantity of water that would have been mobilised to produce internally the same quantities of goods. Therefore this is the marginal water productivity of the site where the decision about producing or not is made, that gives the value of virtual water. The same reasoning holds for deciding to export more; the additional water that needs to be mobilised depends on the marginal water productivity of the production site.

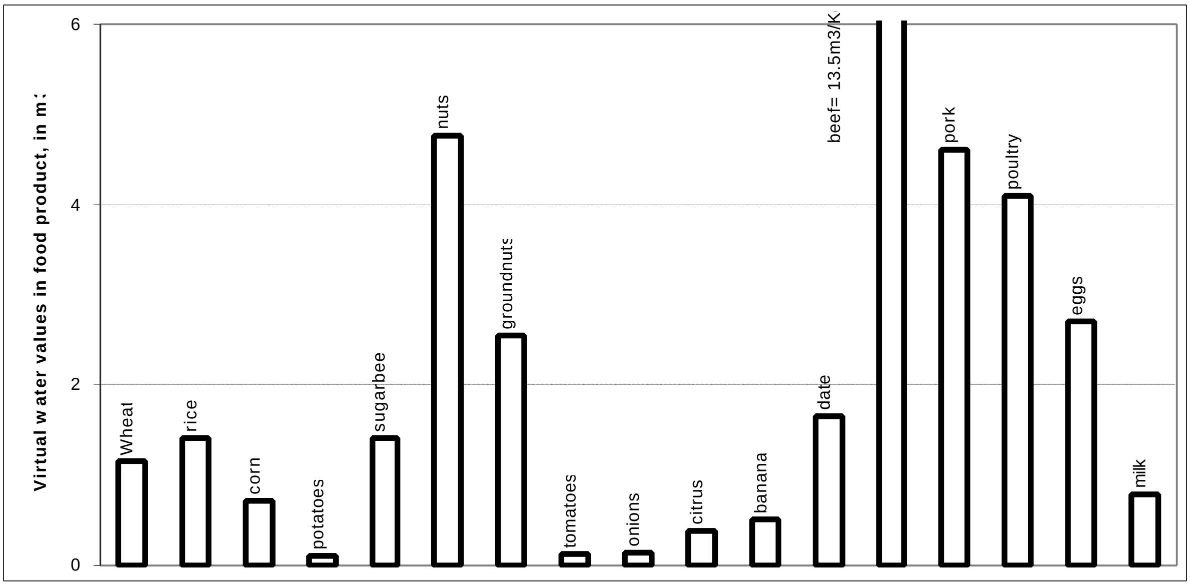


Figure 3.1. Virtual water values for various food products, with reference to Californian production sites - average productivity (after Renault and Wallender, 2000).

Furthermore, as said earlier transfers of food are not limited to spatial transport from production to consumption sites, but cover also time transfers between producing and consuming periods thanks to storage capacity. Thus the value of virtual water of food storage is not the value recorded during the production period but the value at the time of the consumption period.

One major consequence is that Virtual Water Value is neither constant in space nor in time. A more practical consequence of importance is that when food is transferred from high performing production sites or periods to lower performing sites or periods, it generates real water savings. This virtue is illustrated in Section 4.

According to the above definition, a formula of the value of virtual water can be proposed as follows:

$$VWV = \frac{1}{Local\ M\,\mathrm{arg}\,inal\ Gain\ \ of\,Water\ \ \mathrm{Pr}\,oductivity\ (kg/m^3)} \qquad (2)$$

The water productivity of food products is thus central to assess VWV. As water productivity varies a lot with the agricultural conditions, average values over a large area have little meaning for the assessment of VWV. Examples of values of water productivity recorded for cereals in various countries and for various practices are given in Table 3.1. A similar pattern is found for each country; irrigated cereals are more productive than rainfed cereals, and the marginal productivity of supplemental irrigation is high.

3.3. Third principle: The principle of nutritional equivalence

When alternatives are discussed, for instance production vs. import, there are cases for which there is no local alternative to grow the crop under consideration. For example, Germany cannot grow rice, therefore the marginal water productivity of rice has no meaning for this country. The only alternative for Germany would be to produce other products (one or several) that are equivalent to rice. To do that, we need to have a set of indicators that can be used to compare food products. Weight is obviously not the good criteria, we cannot compare one kg of cereals and one kg of tomatoes and the economic value ($) is neither appropriate to this exercise.

In fact the value of any agricultural product in terms of food is measured through nutrients. Therefore the only domain we can think of for equivalence is the nutritional content of food products. The nutritional content is made up of multiple elements; the main indicators being energy, protein, fat, calcium, iron, etc... By introducing the principle of nutritional equivalence we allow comparison of wheat with potatoes for example, or of wheat with a set of products. In Figure 3.2, an example of productivity for energy is displayed for main food products, with reference to water productivity estimated in California. From this figure it can be derived that potatoes are much more productive than wheat: 1 m^3 of water on potato produces the same amount of energy as 2.5 m^3 of water on wheat.

The principle of equivalence states: local alternatives for a food product should be either the same product or a set of other food products leading to the same nutritional values.

Table 3.1. Productivity of water and related virtual water values.

	Productivity of water in kg/m^3		**Productivity of supplemental irrigation in kg/m3** (Blue water)	**Virtual Water Value in m^3/kg**		
	Rainfed agriculture (Green water)	**Irrigated agriculture** (Green and blue water)		**Rainfed** Green water	**Irrigation** Green and blue water	**Supplemental irrigation** Blue water
Wheat Durum Morocco 1985-1986 (Ambri Abdel 1990)	0.7	0.8	1.12	1.45	1.23	0.9
Wheat Durum Tunisia 1986-1987 (Bouzaidi 1990)	0.6	0.85	2.3	1.63	1.17	0.43
Wheat Syria (1987-1990) (Oweis et al. 1999)	0.73	1.28	2.75	1.37	0.78	0.36
Wheat Egypt (Wichelns, 2001)	**	1.32	**	**	0.75	**
Maize France (AFEID, 2001)	1.6	1.9	2.5	0.62	0.53	0.4
Maize India 1981-1985 (Sachan and Smith, 1990)	*	*	0.55	*	*	1.82
Maize Egypt (Wichelns, 2001)	**	0.89	**	**	1.12	**

** data not available; ** in Egypt only irrigated cereals are grown. For comparison the reference average values for California used in Figure 3.1 are respectively VWV wheat = 1.16 m^3/kg, VWV maize = 0.71 m^3/kg.*

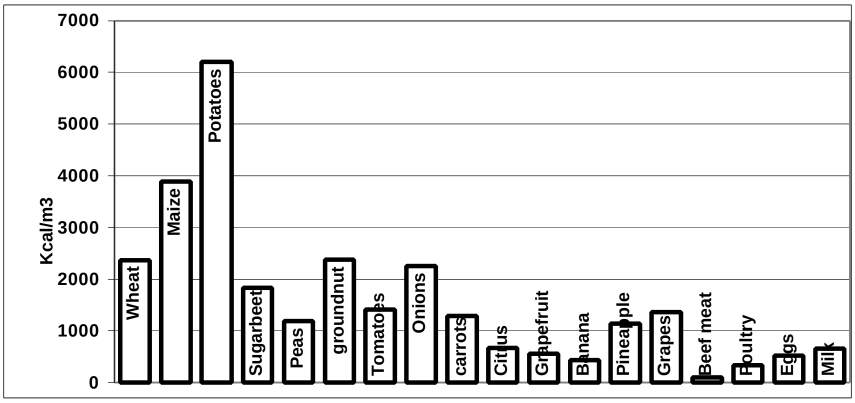


Figure 3.2. Nutritional productivity in energy for various food products (after Renault and Wallender, 2000).

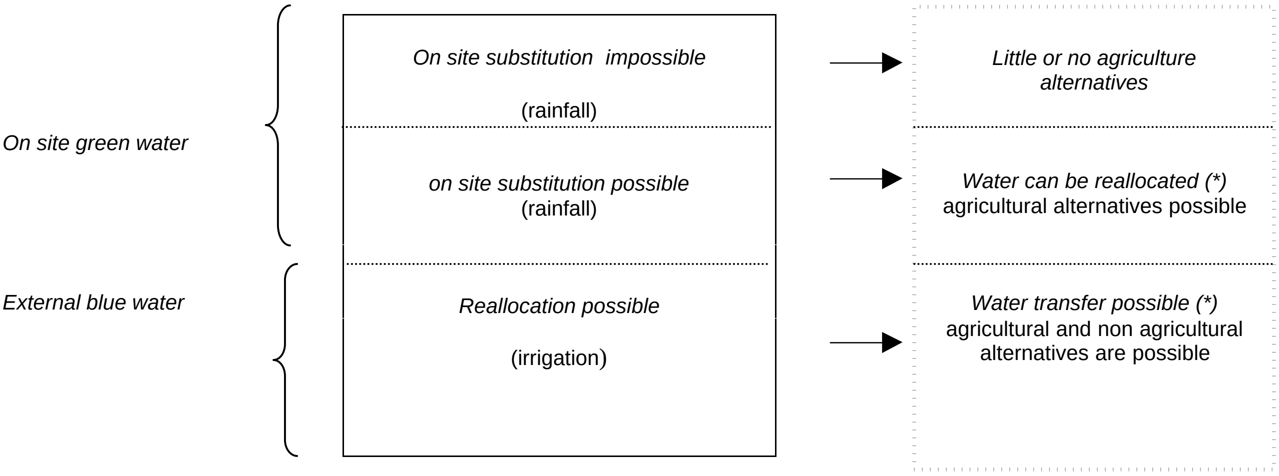
3.4. Fourth principle: The principle of substitution

The potential water savings imbedded in imported food will only materialise locally, if the decrease in food production frees up local water resources that can be made available for other uses. It must be said that this is not always the case. Some water used for crops and food products cannot be substituted with another use of water, as for instance in the case of cattle, which feed on natural rainfed pasture.

Mauritania, for example, is exporting huge quantities of virtual water through the export of goats (140 000 heads in 1994), this country is a net exporter of virtual water (FAO, 1997), which is a paradox for a very arid country. However, any attempt to reduce goat production and exports will be vain as far as water saving is concerned. The herds of goats in Mauritania are taking advantage of a huge territory where little rain can still produce (food or fodder), but would otherwise be lost for production. In this case if there is no substitution for the local goat production – assuming there is no over exploitation of pasture lands and therefore no need to restore natural vegetation – then the impact of virtual water in the decision process is irrelevant.

The question of substitution is important for virtual water. In Figure 3.3, a grid of possible situations in that respect is presented. The Mauritania case mentioned previously is an example of the top box in Figure 3.3.

In fact the principle of substitution is already included in the principle of the marginal gain. When no substitution is possible, the marginal gain is simply set to zero, which means that the potential of savings is nil. However, for the purpose of clarity we maintain the two principles separated.



(*) Transfer and reallocation are bounded by bio-physic conditions of the watershed.

Figure 3.3. Analytical sketch of the substitution principle in the production domain (after Renault, 2002).

3.5. Fifth principle: The principle of deflation

Historical approaches are important for studies on food trade and food consumption as well as those related to water management. It is important to look at past evolution of fluxes to identify trends, noticeable breaking points, and also to allow more accurate projections. The problem comes from the fact that productivity of water is not constant with time, therefore the values of virtual water (VWV) varies with time.

As productivity of land and water has increased significantly in past decades, virtual water values have decreased in the same proportion. Therefore constant values of VW cannot be used for historical analyses. VWVs need not only be reliably assessed for one time period, but also their evolution over the past need to be indicated. An example is given in Figure 3.4, which illustrates the gain in yield for wheat recorded in France. This evolution of yield (3% per year) is quite representative of the water productivity gains during that period as wheat is mainly rainfed in this country; i.e. the increase in yield occurred with hardly any variation in water consumption. The wheat yield has tripled between 1961 and 2000, and as a consequence the virtual water value of wheat in France has been reduced in 2000 to one third of its 1961value.

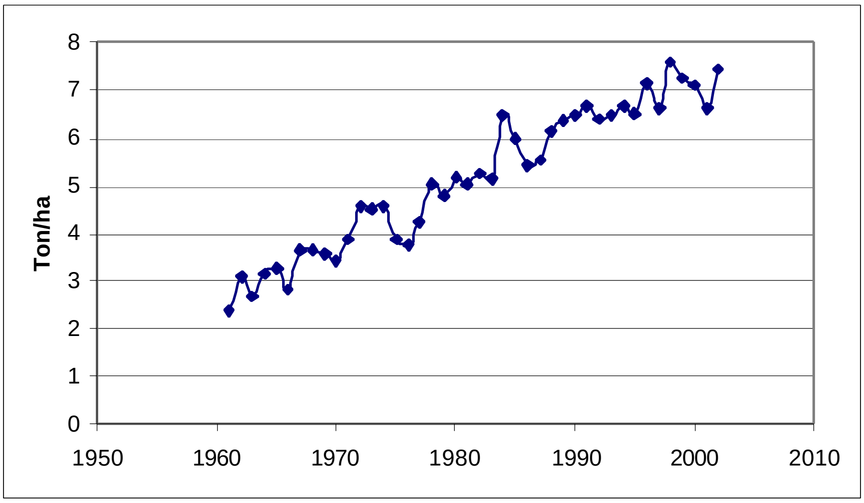


Figure 3.4. Recorded wheat yields in France between 1961 and 2000 (FAO database).

3.6. Virtual water value

To summarise the previous points, one can say that the whole debate on the value of virtual water is about water productivity and its variation in space and time. The value of virtual water of a food product is site and time specific and equal to the water that would have been consumed locally to produce the same quantity of nutrients. For global studies and comparisons, there is a need though to have common values (first principle) of water productivity and VWV. For decision making analysis, on the other hand, only local productivities and VWV (second principle) must be considered.

The previously described principles can be put into the following formula:

$$VWV\ (\mathrm{m}^3/\mathrm{kg}) = Marginal\ local\ water\ consumption\ [x,y,t,\ product] \tag{4}$$

Where

x and y	express the variation of the VWV with the location
t	expresses the variation of VWV in two ways, variations of water productivity with agro-climatic years, general trend of deflation due to the continuous water productivity gain,
product	expresses the alternative in terms of products having same nutritional values.

Summarising the previous, the following definition for VWV is proposed:

Virtual water value of a food product is site and time specific and equals to the marginal water requirements for a local alternative production of the same quantity of product or its nutritional equivalent.

4. Applications and features of virtual water

In this section it will be illustrated how the five principles can be applied, underlining some features of virtual water.

4.1. Computing virtual water trade at global level

Virtual water trade can easily be computed by combining data on trade with data on virtual water values. Using values of virtual water adapted from Renault & Wallender (2000), it is estimated that for 2000 the global water requirements for agricultural food products amounted to 5200 billion m^3, and the virtual water trade totalled 1260 billion m3; i.e. 25% of the total water use for food. The latter figure includes animal product trade for 390 billion m^3, and crop trade for 870 billion m^3, a figure rather close to the 695 billion m^3/yr found by Hoekstra and Hung (2002) for the period 1995-99.

Figure 4.1 shows the breakdown of virtual water transferred around the world per main type of agricultural product. This figure is quite interesting because it shows that cereals, which have captured most of the attention in food security and virtual water studies, account only for 24% of the total volume of virtual water exchanged. Of course when it comes to nutritional values, and for arid regions, the importance of cereals is much greater than one fourth. In 2000, cereals contributed to 40% of the food energy trade (Zimmer and Renault, 2003).

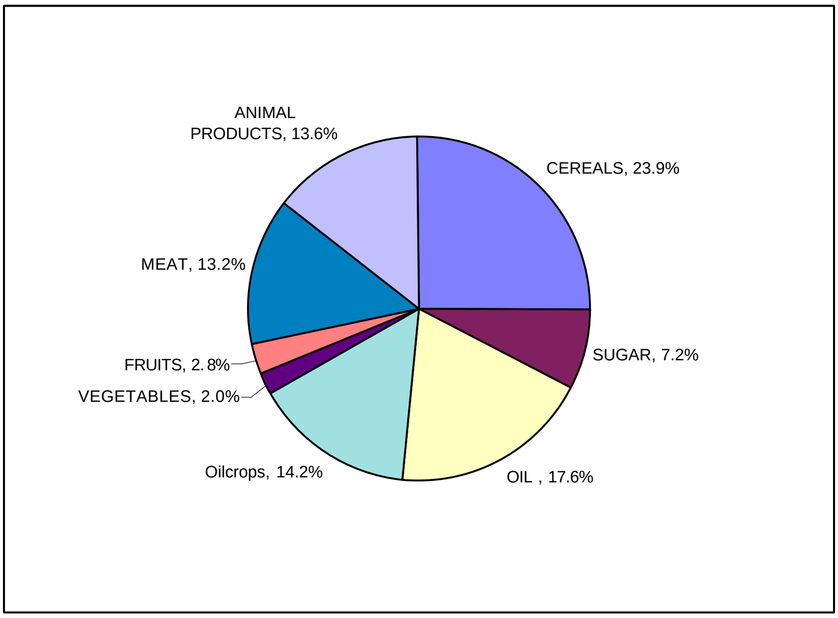


Figure 4.1. Global virtual water trade partitioned in main types of agricultural food products.

4.2. Applying the principle of marginal gain in estimating virtual water

The alternatives to import/export are respectively increase/decrease of internal production. When considering increasing internal production of a given food product, leaving out investing into techniques for yields improvement which are long term actions, there are basically three options with immediate effects:

- expanding rainfed production areas
- expanding irrigated production areas
- transforming rainfed areas into irrigated areas.

Corresponding water productivities are of course different, and furthermore within each option productivity of water varies with the local situation. Usually the more productive internal sites are already used and therefore the expansion of areas occurs on land that deviates from the average fertility conditions. The water productivity curves for additional input being land or water are often declining. Figure 4.2 shows water productivity curves as function of additional unit water used, for rainfed and irrigated practices. These curves are of course site specific, but often the slope of decline of water productivity for rainfed conditions is higher than for irrigation, because the soil water storage capacity is critical for yield.

Assuming that productivities of existing production systems lie between A and B for rainfed and between C and D for irrigated agriculture (Fig.4.2), the options for production increase and corresponding productivities are:

- Option 1 expand rainfed production areas (Point B): marginal productivity equals to WP2
- Option 2 expand irrigated production areas (Point D): marginal productivity equals to WP4
- Option 3 transform rainfed areas into irrigated areas: marginal productivity jumps from AB to CD (on average from WP1 to WP3)

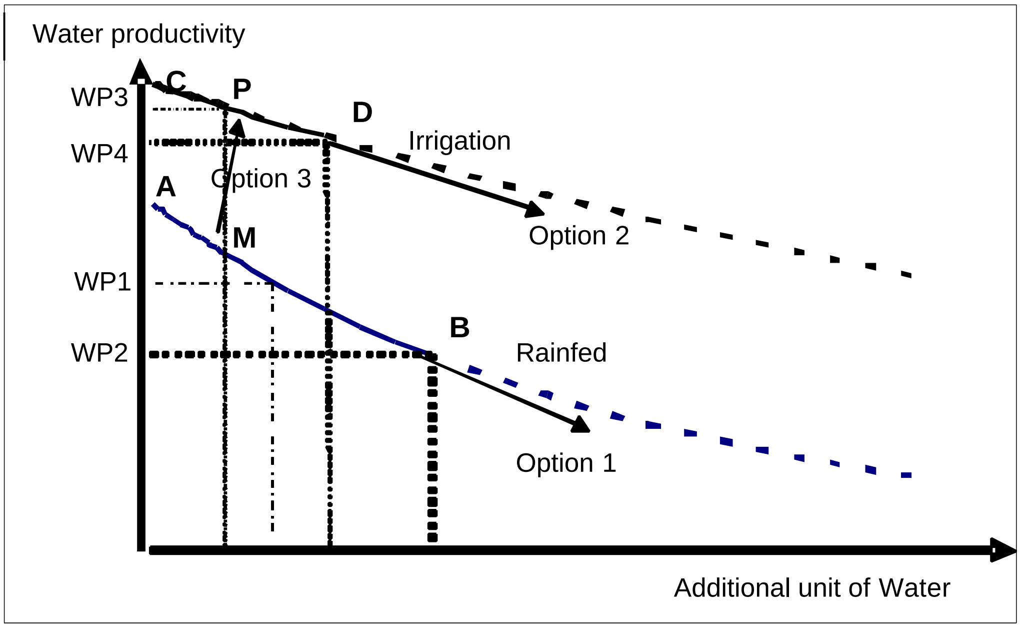


Figure 4.2. Water productivity curves per unit of water

With the example of maize in France (see Table 3.1), the average productivity of rainfed area (WP1) amounts to 1.6 kg/m^3 and the average virtual water value against this option is 0.62 m3/kg. As shown in Figure 4.2, the marginal water productivity value can be lower than this value (e.g. -25%), hence the VWV would be greater (respectively +25 %). The same reasoning holds for the irrigated maize expansion although the expected variation of productivity is lower for irrigation than rainfed. If expansion happens on lands close to the average conditions then the average productivity will apply 1.9 kg/m^3 and the VWV will be 0.53 m^3/kg, and if the expansion occurs on less fertile soils, VWV will increase (e.g. +10%).

Finally, transforming rainfed to irrigated areas will lead to benefit from the high productivity of supplemental irrigation (average 2.5 kg/m^3) and corresponds to a low virtual water value of 0.4 m^3 of water per kg. The marginal gain from rainfed to irrigated conditions can deviate from average by a positive or a negative deviation.

The average VWV for maize in France is thus ranking from 0.4 to 0.62 m^3/kg, and the marginal VWV is likely to be within 0.4 to 0.8 m^3/kg. An increase of production in France would certainly combine different options, thus a value of about 0.6 m^3/kg can be used as the value of virtual water for maize in France.

4.3. Virtual water imports generates real water savings

The most straightforward effect of virtual water is about water savings for the countries or the region that imports food products. This effect has been widely stated in virtual water studies (Allan, 1999). The savings are directly the result of the quantity of imports multiplied by the value of virtual water estimated using the marginal gain principle.

Water savings (m^3) = *Import* (kg) x *VWV*(local site) (5)

For instance, Egypt imported some 5.2 millions tons of maize in 2000. With a VWV for maize estimated at 1.12 m^3/kg (Table 3.1) this represents a water saving of 5.8 billions m^3 of water from national allocation, i.e. about 10%.

4.4. Virtual water trade generates global real water savings

As the value of virtual water varies with location, virtual water does not obey to the mass conservation law. Food trade generates transfers of virtual water having variable values. In many cases (but not all) these transfers occur from high performing production sites to lower performing sites, which lead to real water savings as a whole. The water saving corresponds to the differential of productivity between the production site and the consumption site.

$$\textit{Water savings}\ (\mathrm{m^3/kg}) = \textit{VWV}(\text{consumption site}) - \textit{VWV}(\text{production site}) \qquad (6)$$

For instance, transporting 1 kg of maize from France (taken as representative of maize exporting countries for water productivity) to Egypt transforms an amount of water of about 0.6 m^3 into 1. 12 m^3, which represents globally a real water saving of 0.52 m^3 per kg traded. The maize imports in Egypt and the related virtual water transfer have thus generated a global saving of about 2.7 billions m^3 of water in 2000. The global real water saving is quite significant: a first rough estimate at global level shows that water savings due to virtual water transfer through food trade amounts to 455 billions of m^3 (Oki *et al*., 2003).

The assumption of virtual water flowing from high to low productive sites is not always met. Some countries are facing limitations in allocation of water resources for food or in another input for agriculture (land, labour,..). Thus despite sometimes having high productive agricultural sites, countries must import food products from countries with lower productive sites but benefiting from greater resources. This is the case of Egypt which has high water productivity for pulses but still imports large quantities of pulses, mostly from USA where productivity is much lower. In that particular case the imports of pulses (260 000 tons in 2000) save in Egypt some 450 millions m^3 of water, but consumes in producing countries around 760 millions of m^3. Resulting thus in a net additional consumption at global level of 310 millions m^3. This example illustrates the fact that equation 6 can be sometimes negative, although the global trend is that virtual water trade saves real water.

4.5. Food storage generates real water savings

As said earlier VWV varies with the climatic season. Again the mass conservation law does not apply for food transfer in time. In most cases storing food is made during wet and highly productive years, whereas tapping the storage occurs during dry and low productive years. The water saving corresponds to the differential of productivity between production and consumption periods.

$$\text{Water savings (m3/kg)} = \text{VWV(storing period)} - \text{VWV(using period)} \qquad (7)$$

For instance in Syria, the year 1988 has been a good year for the cereal production with high yields (1.6 ton/ha) leading to a volume of production higher than consumption, thus 1.9 million ton of cereals were stored during that year. The following year was a very dry one, and the cereal yield dropped to a low 0.4 ton/ha. A volume of 1.2 million ton of cereals has then been used from internal storage to complement internal production and imports. Water productivities recorded these years has been estimated to 1 kg/m^3 for 1988 and 0.3 kg/m^3 for 1989 (Oweis, 1997), which corresponds respectively to VWV of 1m^3/kg to 3.33 m^3/kg. Thus the use in 1989 of 1.2 million ton of cereals from storage is equivalent to 4 billion m^3 of virtual water. On a two years period of reference (88-89) some 2.8 billion m^3 of water has been saved by the food storage capacity.

One major conclusion here is that the value of virtual water stored in food must be estimated using the low productivity years. Thus the virtual water value of the global food grain storage estimated in the introduction part using average value (500 billion m3 of water) must be hold only as a minimum.

4.6. The high value of virtual water of sea products

The sea products (fish and others) contribute significantly to the food supply and the food trade. Although the process of production of sea products does not imply water consumption, it would not be wise not to account for their virtual water values. Importing and consuming sea products corresponds to a virtual water consumption which needs to be estimated through local alternatives.

Here, the principle of equivalence (third principle) is used to identify a set of products equivalent on nutritional properties that could replace sea products. The average nutrient content of a kg of sea product is 640 Kcal/kg - 98 g protein/kg – 23 g fat/kg. Because of the specific nutritional properties of sea products - high in protein and low in energy and fat – the equivalence must be made considering on one side sea products plus some energetic product such as cereal or sugar, and on the other side a set of products as the alternative.

Obviously there are many options to reach the equivalence. An alternative for vegetal products is the result of increasing intake from pulses for protein, and oil for fat and a significant decrease from cereals. Simulation shows that the virtual water value of the equivalent set would be in that case approx. 1.5 m^3. It must be underlined that equivalence on energy, protein and fat is only part of the spectrum. There area many other micro nutrients in sea products which are not supplied by pulses, this is obviously one limitation in replacing sea products by vegetal products. To increase the equivalence fit would require a more diversified set of vegetal products and therefore would increase the value of virtual water. It seems therefore reasonable to set the equivalence for vegetal at around 2 m^3/kg.

Alternatives for sea products based on animal products (beef, pork, poultry, eggs and milk) lead to a value of virtual water of around 5 m^3/kg. The equivalence of animal products to sea products is generally considered by the nutritionists as better than for vegetal products.

As a conclusion it is proposed to associate a virtual water value for sea products adapted to the local food diet and specifically to the balance between animal and vegetal products. VWV for sea products would then range from 2 for vegetal products to 5 m^3/kg for animal products.

Using the animal products alternative (5m^3/kg) the weight of sea products is 8% of the global virtual water budget and 14 % of the global virtual water trade (Zimmer and Renault, 2003)

4.7. Impacts of diet changes on water requirements

The impact of diets on water requirements for food is significant because food products have variable virtual water contents, as illustrated in Figure 3.1. Beef meat has a high VWV around 13 m^3/kg whereas cereals vary around 1m^3/kg. Food diets and habits vary among cultures and with economic development. Usually countries, the economy of which are developing tend to see consumers going for more meat and less cereals. This trend is obviously putting more pressure on water resources for food production. However, in developed countries the growth in water for food recorded during the sixties and seventies is slowing down.

Figure 4.3 depicts the evolution of water requirements for food per capita in fifteen European Union countries (EU15) for the years 1961 up to 2000, using constant virtual water values estimated for 1990. One can see that up to 1980 water consumption per capita for animal products was on the rise, while that for vegetal products remains constant; the total being a significant rise of water needs from 3340 to 4050 litres/day/capita. After 1980 the opposite occurs: water for animal products stays constant while it increases for vegetal products, and the total slightly increases to 4240 litres/day/capita. Within animal products, beef meat consumption reached a high peak in 1980, and the reduction since then has been compensated by increase pork and poultry. The increase in vegetal product since 1980 is mostly driven by the increase in oil consumption.

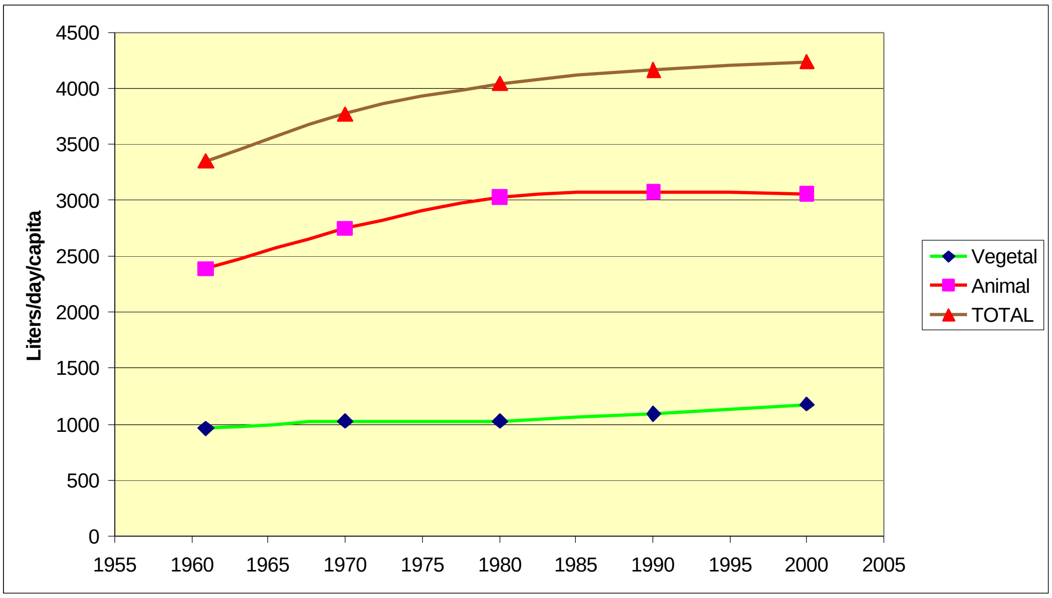


Figure 4.3. Impact of changes in food habits on water requirements, through the evolution of water for food in European Union (EU 15), with constant virtual water values (References 1990).

4.8. The historical decline of water needs for food

Without further care, we could have said from the above analysis (Figure 4.3) that water requirements for food have increased for EU by 900 litres/day/capita between 1961 and 2000. However this analysis does not considers the gain in water productivity of cereals (Figure 3.4) and of other food products, therefore using constant VWV of 1990 might be absolutely misleading.

In fact yields of maize in Europe have been raised by an averaged 3.3 % increase per year between 1961 and 2000. At least part of this gain of grain yield productivity has been converted into gains of water productivity. The question remains of course how much of the yield gain is converted into water productivity increases, knowing that on the one hand, producing more biomass requires more transpiration, on the other hand the ratio of grain to biomass has also been increased consistently. Thus this question is difficult to answer with certainty. It obviously requires more attention to come up with reliable assumptions.

In Figure 4.4, the evolution of the virtual water content in food consumption for developed countries is given with 2 options for productivity gain. One considers that the entire gain in yield (3.3%) has been converted into water productivity gains, which is of course extreme. The other considers that the increase of water productivity reaches 50 % of the yield growth (1.65 %).

This shows that the previously mentioned increase in water consumption per capita from 1961 to 1990 (VWV 1990 in Figure 4.3) does not reflect reality. With the 1.65 % deflated rate, which is a conservative assumption about water productivity gain, water consumption from 1961 up to 1990, has decreased steadily in the European Union from 5400 to 3600 litres/day/capita: a huge water saving of 1800 litres/day/capita. Further detailed studies should be made to give more accurate figures on which deflation rates per product should be considered. What seems to be quite clear though is that water for food per capita in Europe has been reduced by thousands litres per day. Similar patterns are found in many countries including USA and at global level.

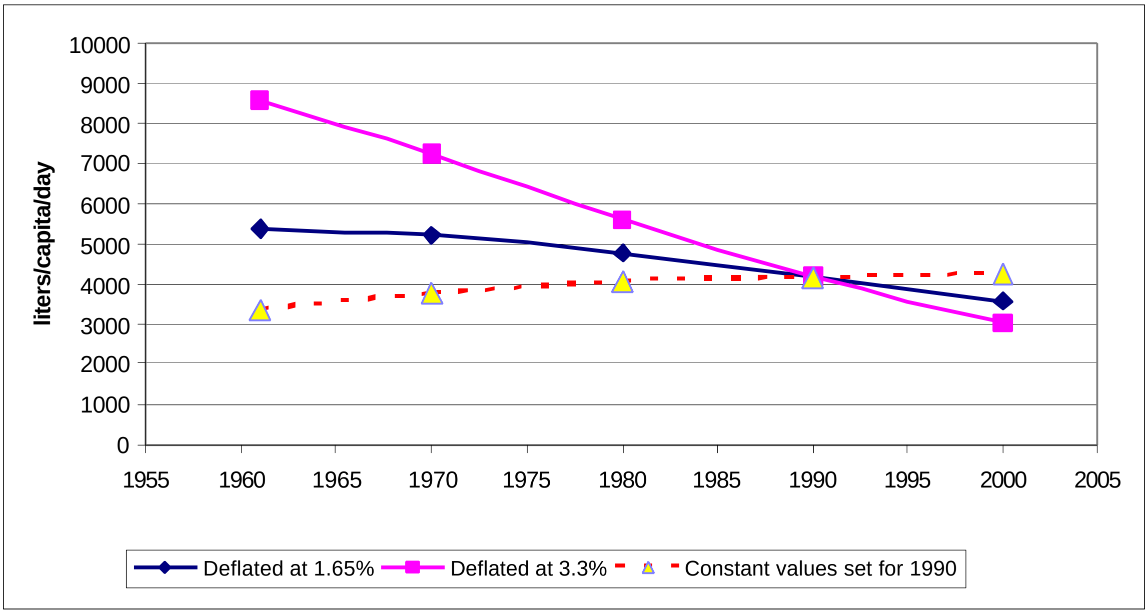


Figure 4.4. Evolution of virtual water content for food in the European Union, with various deflation rates of virtual water values (reference 1990).

5. Perspectives

Again it is important to recall that decisions on importing/producing any good, and in particular food products, are not only based on the virtual water value as described in previous section. However it is important that virtual water is properly assessed in terms of its value in space and in time.

One of the following steps should consists in defining accurate common virtual water values, and setting reliable methodologies for computing volumes of virtual water embedded in food trade, particularly looking at the way to deal with secondary products like meat to avoid double counts of primary and transformed products (meat, oil, sugar, etc..). Another step would be to analyze how virtual water is considered at policy level on food trade, water management and agriculture.

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5

Virtual water in food production and global trade: Review of methodological issues and preliminary results

D. Zimmer and D. Renault

1. Introduction

The water consumed in the production process of an agricultural or industrial product has been called the 'virtual water' contained in the product (Allan, 1998). If one country exports a water-intensive product to another country, it exports water in virtual form. In this way some countries support other countries in their water needs. For water-scarce countries it could be attractive to achieve water security by importing water-intensive products instead of producing all water-demanding products domestically (WWC, 1998). Reversibly, water-rich countries could profit from their abundance of water resources by producing water-intensive products for export. Trade of real water between water-rich and water-poor regions is generally impossible due to the large distances and associated costs, but trade in water-intensive products (virtual water trade) is realistic (Hoekstra and Hung, 2002). Virtual water trade between nations and even continents could thus ideally be used as an instrument to improve global water use efficiency, to achieve water security in water-poor regions of the world and to alleviate the constraints on environment by using best suited production sites (Turton, 2000).

Virtual water has not attracted much research so far. What are the volumes involved? Do these volumes represent a significant part of the blue or of the green water volumes used in agriculture? What are the current tendencies? Which are the countries exporting most of the virtual water and which are the ones that import it? Which are the products responsible for the most important transfers? There is even no clear methodology to evaluate the virtual water contents of food products.

An attempt was made to quantify these volumes. This paper presents results as well as preliminary comparisons with the results obtained by Hoekstra and Hung (2002). The method utilized is also presented and discussed. It should be pointed out that quantifying the volumes of virtual water is not straightforward because water productivity is variable in space and time. Thus, when assessing the virtual water traded between two countries, one can estimate either the water actually used by the country exporting the food product or the water saved by the country importing it. In many cases these transfers occur from high performing production sites to lower performing sites, which means that globally real water is saved (Oki *et al.*, 2003). It has been estimated that not only Egypt saved 5.8 billions m3 of water from national allocation in 2000 through maize imports, i.e. about 10% of its annual allocation, but globally a saving of 2.7 billion m^3 of real water is generated thanks to the differential of productivity between maize exporting countries and Egypt (Renault, 2003).

These concepts have however not been used in the present work due to the amount of data needed to estimate these volumes. The perspective was more simply (i) to provide first estimates of the virtual water transfers based on a unique set of references and the relative share of different types of traded food products, and (ii) to identify the difficulties as well as important assumptions needed to compute virtual water volumes.

The first part of the paper looks at methodologies whereas the second part focuses on preliminary results on world assessment of water embedded in food products and of traded virtual water.

2. Methodological issues

In this section an attempt is made to point out the methodological steps that need to be properly addressed when estimating virtual water in food consumption and in food trade. Aggregating virtual water content from crop water consumption at field level up to the global banquet is a path along which many assumptions must be made. Therefore the first rule if any in studies on virtual water is to clearly specify assumptions and accounting procedures used.

This section draws on recent studies made by the authors and lists some of the important points that one needs to bear in mind when assessing virtual water. This is a preliminary attempt to come up with comprehensive accounting procedures for virtual water budget. This section on methodologies is complementary to the set of principles proposed by Renault (2003) for assessing the value of virtual water.

Five major steps need to be considered:
- categorise food products with regards to processes and their virtual water value
- properly map the fluxes of products within and at boundaries of the system considered
- specify the production processes for each type of food product
- specify the scope of the study
- compute virtual water content and flows.

2.1. Characterising food products for virtual water studies

Almost all food products consume water as part of their production process, however the amount of water required per unit of production depends largely on the type of product. If the relationship between production and water consumption for instance through evapotranspiration, is often clear for crops, it can be quite fuzzy for other processes. This is why it is important to introduce some distinction in the food products, and sort them by pertinent criteria for virtual water content assessment.

2.1.1. Primary product

Cereals, vegetables and fruits fall into this category for which the relationship between water consumption and production is quite clear. Production (kg) and water evapotranspired (m^3) are estimated at field level and are the basis of the virtual water value estimation (m^3/kg), possibly adjusted with efficiency factors. These products are assessed as primary products even though sometimes transformed afterwards (e.g. fruit juice).

2.1.2. Processed products

These are the food items that are produced by processing primary products. Vegetal processed products include sugar (sugarcane, sugar beet), oil from various primary product, and alcoholic beverages.

2.1.3. Transformed products

Animal products must be considered as transformed products as their production using primary vegetal products (cereals, grass, other by-products).

2.1.4. By-products

These are food products which are produced by crops grown primarily for other purposes than their nutritional values. An example of by-product is cotton seed which is used to produce oil, while cotton is grown mainly for fibre production.

2.1.5. Multiple-products

Some agricultural products are grown not for one purpose but for many purposes. This is the case of coconut trees in South Asia, the products of which are used as materials for house building, raw material to produce sugar, coconut fruit, ropes, etc…. not including the environmental value of the perennial vegetation. In that case water consumption of the trees must be split into various uses of water, with no one being dominant. This is also the case for some animal production which goes beyond meat production (leather, offal, fat for industry, etc…).

2.1.6. Low or non-water consumptive product

In this category, we find mainly seafood and sea fish for which no water consumption can be associated with their production. Inland fisheries can consume small quantities of water through water evaporation of natural streams and bodies, and sometimes through the vegetal primary products used to feed the fish.

We also find in this category some animal production which are fed by crop residues and various wastes from family consumption. For instance in China about 80 % of the pig meat production (454 million heads) is of this type (backyard production). It is quite difficult to estimate the real water consumption for this type of products. For this category, despite a low or nil real water consumption, an equivalent value of virtual water can be identified using the nutritional equivalence principle (Renault, 2003).

2. 2. Mapping the fluxes of products

As done for any other water accounting approach (e.g. hydrology at basin level) it is crucial to map the boundaries of the system under consideration, identify the fluxes and the stocks inside the system and at its boundaries.

To that end, it is important to dissociate primary and secondary products to account for stock variations and fluxes, for waste, seeds, and others uses (industrial). A simple illustration of this mapping is given in Figure 1.

One of the difficulties with processed products is to make sure that there is no duplication in the values utilized to ensure that a given quantity of water is not accounted for in different products. For instance, cereals used to feed cattle should not be counted twice, once in the cereal production and second in the meat production.

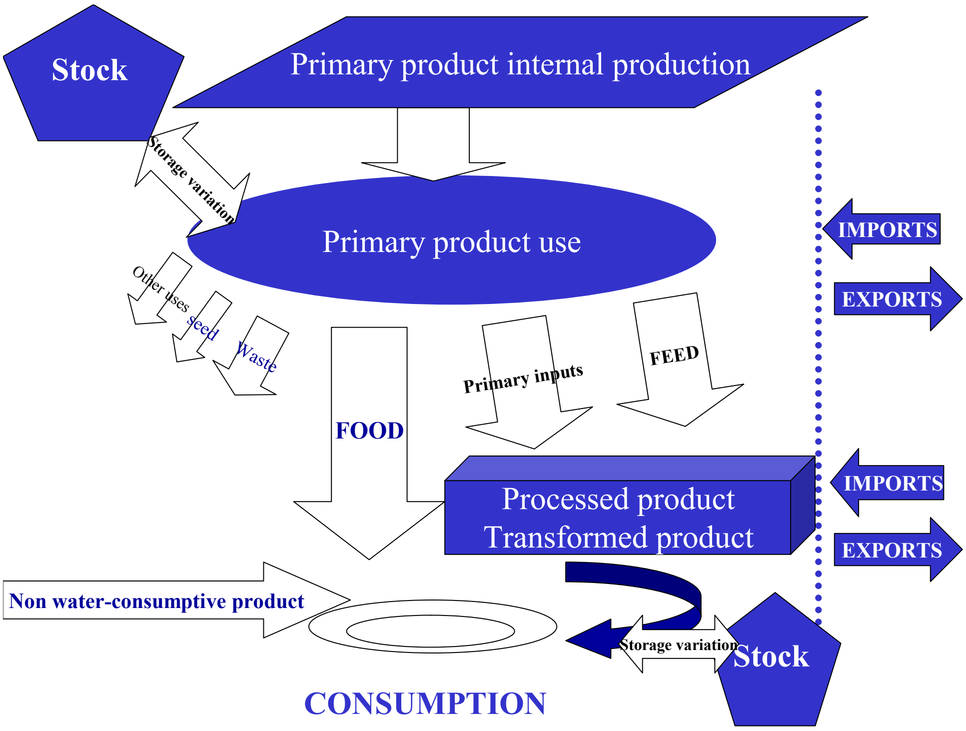

Figure 1. Mapping food product fluxes.

2.3. Specifying the efficiency of the processes

It is important that for each product, the processes are well understood and that all components being accounted for. Although quite simple for annual crop production it can be more complex for perennial vegetation and processed products. The goal here is to lead to the best approximation of water consumption and food production.

In so doing at least three efficiencies must be considered.

- **Water efficiency**: In most studies on virtual water for food, the basic value of virtual water only considers the water evapotranspired at field level. However for irrigated agriculture, water losses either for the field application or during the distribution must be considered if there is no possibility of recycling these losses at basin level. It might be useful to introduce a correction coefficient to include them as proposed by Haddadin (2003). Furthermore water leaching sometimes required in arid areas to deal with saline water must also be considered as water consumption.
- **Production efficiency**: for multi annual food products the period and the level of production vary with time. The estimation of the virtual water value must take account total production and water consumption

during life span. For instance for perennial vegetal products, or for dairy production, the effective period of production is reduced as compared to life span, and this must be considered as a reduced production efficiency compared to peak yields.

- **Consumption efficiency**: production at the farm gate does not entirely convert into consumption because of various wastes before reaching domestic consumption, and also the process itself of food consumption generates its own waste. This is particularly true for fresh products (vegetables fruits) which are sensitive for conservation.

As compared to virtual water, we must note that real water content in the final product (even for tomatoes) is always negligible, and so is water required by the transformation or processing of the products. Drinking water for a bull is less than 1% of the water requirements for feed (Barthelemy *et al.*, 1993) and is not entirely a consumptive use.

2.4. Specifying the scope of the virtual water study

Assessing the embedded water content in food products at global level can be made by considering various options and serving various purposes. It is important that these options and purposes be clarified to avoid confusions.

Three options at least can be considered:

- Assessing real water requirements to produce the food needed at global level
- Assessing the value of virtual water in food consumption and in food trade
- Assessing the value of virtual water in trade policy and its impacts on water savings at national and global levels.

The procedures behind these three options might differ significantly as will be illustrated hereafter. Because some food products do not require water in their process or are produced from waste products, the real global water requirements are always lower than the total value of virtual water worldwide.

2.5. Computing virtual water content

The computations are made considering the different categories specified in Section 2.1.

2.5.1. Evaluating virtual water of primary products

The principle of calculation of water productivity is rather simple: crop water requirements ETa (m^3/ha) are calculated from the climatic demand (ET) adjusted with crop coefficients. Software like CROPWAT (FAO, 1992) can be used for this purpose. Water productivity is then obtained by dividing the crop yield Y (kg/ha) by these crop water requirements. Virtual water value, the inverse of water productivity is then given by the following equation:

$$\mathrm{VWV} = \frac{\mathrm{ETa}}{\mathrm{Y}} \tag{1}$$

2.5.2. Virtual water of transformed and processed products

The assessment of virtual water content of transformed and processed products pose specific problems linked to the yields of the processes utilized and to the fact that primary products may be used to produce various products. Animals are classified in this category and pose also difficulties due to the various allocations of their meat and by-products.

Vegetal transformation usually is made considering both a processing yield factor (kg of primary product amount to produce 1 kg of end product) and the virtual water value of the primary product.

2.5.3. By-products

For this category, different methods of estimation of virtual water are possible:

- A first method consists in allocating virtual water of all sub-products proportionally to the quantities produced; for instance, each kg of cotton provides 0,625 kg of fibre and 0,375 kg of cotton seed and the water consumed is allocated proportionally to these values;
- A second method consists in allocating virtual water proportionally to the economic values of the various products. This second method may seems preferable but it has also some drawbacks: (i) the economic values may be quite variable in space and time; (ii) in case of by-products, the value may be very low because the product has little attract for the market and cannot be substituted to another product.
- A third method consists in dissociating the value from the real process, and to determine the value of virtual water by considering the **nutritional equivalence principle** (Renault, 2003). For instance in the case of cotton oil, it consists in affecting the value that is recorded for another oil product.

2.5.4. Multiple products and non water consumptive products

For these two last categories of products associating the food product to real water consumption is difficult. It is proposed to dissociate virtual water from the real process and estimate the virtual water value with the nutritional equivalence principle.

Regarding sea products and most of the fish (except inland fisheries), the production does not consume any water through evapotranspiration. Thus these products can be accounted for either with a nil virtual water value or with the virtual water content of other agricultural products by which they can be substituted. This is the assumption adopted here. With this assumption, virtual water value of sea food products and fish has been evaluated at 5 m^3/kg with an equivalence based on alternative animal products equivalent for energy and proteins (Renault, 2003). As we will see hereafter, the share of sea food and fish products in virtual water trade is important (14%).

This method applies also for other transformed products, when accounting for primary product is difficult or pointless. Examples of that are cattle on grazing lands (not easy to account for grass) or backyard animal production such as pigs in China.

3. Data and method used

3.1. Production, use and trade of food products

Various sources of data have been utilized:

(1) The annual food balance sheets from FAO were the major source of data: this database contains information related to production, imports, exports and stock changes for most countries in the world. In addition, it also provides data related to the type of use of most food products; uses are split into the following categories: food, feed, seed, processing, waste and other uses. Data are available for the period 1961 to 1999.

(2) The TS database from USDA was also utilised mainly for comparison with the FAO data. TS database provides data related to production and trade of most crops all over the world. In most of the cases the data provided by the two sources compared very well as shown in Table 1. As a result whenever data where missing in the FAO database, they were taken from the TS database.

(3) A few data available in various publications were also utilized. In general these data confirmed that the FAO data were quite accurate.

Table 1. Comparison of a few data from FAO and TS databases (in 10^3 T) (Year 1999)

	Products	FAO data			TS database		
		Production	Imports	Exports	Production	Imports	Exports
World	Wheat	585410	130483	134036	580674	125779	126927
	Palm oil	21019	14541	16181	21795	13991	14656
Asia	Wheat	259199	47987	7704	209511	28958	1946
	Palm oil	17768	8660	13858	18500	7869	13201
Egypt	Wheat	6347	6053	21	6350	5973	0
	Palm oil	0	561	0	0	455	0

In this study, we are using a set of data on virtual water values which have been estimated considering some of the exporting countries having high productivities. Most data are derived and adapted from the work of Barthelemy *et al*. (1993) referencing mostly to the following countries: California, Egypt and Tunisia (See Tables A1 and A2 in the Appendix). Precise values of specific water demands had been derived for this purpose for several crops, processed and transformed products in California in 1990. Other values have been obtained from various papers or databases.

The most important food products have been parameterised for this work. However, three types of products have not been accounted for in the calculations:

- Spices, coffee, cocoa and tea; these products should be included in future calculations;
- Fibre crops (e.g. cotton) have also not been included, but their side-products included in food chains have been included
- Grass production used to feed cattle has also not been considered.

4. Global and continental results

4.1 Principles

The procedure utilized consisted in:

- For the global water requirements, estimating the use of water for primary vegetal products (Table A1, Appendix). In fact this was possible for most of the products except for a few oil products (coconut oil, palm oil, palm kernel oil and sesame seed oil) for which the production of raw products was not available in the data base. For these products, the virtual water content of the transformed products was utilized (Table A2, Appendix).
- Estimating the total content in virtual water of all products imported or exported by a country.

Using only the primary vegetal products leads to an underestimation of the total water utilized for food production for each country since some important products are not included (like grass).

Finally, since the specific water demands had been estimated for 1990, a correction factor was introduced to account for the increase in water productivity. Estimations were carried out using an annual increase in water productivity of 1 %.

4.2 Global values

A first estimate of virtual water budget and trade has been made at global scale using the approach presented above (Table 2).

Table 2. Water consumed for crop production and virtual water traded between countries at global scale for years1989, 1994 and 1999 assuming an annual increase of 1% in water productivity.

	1989		1994		1999	
	km^3/yr	m^3/cap/yr	km^3/yr	m^3/cap/yr	km^3/yr	m^3/cap/yr
Consumed water of cropped products	3569	697	3626	650	3777	632
Traded virtual water	1008	197	1111	199	1247	209
Ratio of traded virtual water versus consumed water	28%		31%		33%	

As compared to a total value of 5200 km^3 (see hereafter), the order of magnitude of 3700 km^3 of water embedded in food production seems correct if we recall the fact that only crops are considered (grass and natural pasture not included). This value compares also relatively well with the 3800 km^3 of water resources mobilised as "blue water" and with the 1800 km^3 of water consumed by irrigation (out of a total of 2500 km^3 withdrawn; Cosgrove and Rijsberman, 2000).

Although based on a different set of data (since it includes many transformed products), the order of magnitude of the virtual water traded between countries seems also consistent with the total water volumes used for food production. The ratio of virtual water traded versus water consumed by cropped products represents about 30%. When comparing to the total value of 5200 km^3, this ratio is 23%. This undoubtedly has an impact on the management of water resources at global scale. It can also be noticed that the share of virtual water traded increases significantly with time, despite a decrease of values thanks to the increase of water productivity of 1%.

Finally, it should be pointed out that at global scale the water consumed by crop production represents about 2 m^3/day/cap with a regularly decreasing trend[1]. Since the cropped products per capita has remained constant during the period considered, the trend represents exactly a decline of 1% per year which correspond to the assumed annual increase in water productivity.

5.3. Continental values

Using the continental values of the FAO database and the same method, a comparable estimation has been conducted. Results for 1999 are presented in the following tables in km^3/year (Table 3) and in m^3/cap/year (Table 4). Due to consistency problems in the database, it has to be noted that for Europe, former Soviet Union Countries was excluded from the analysis.

Two continents, America and Oceania, are net exporters of virtual water. They represent 51% of the exported virtual water. In particular, the exports of Oceania are much more important than their own consumption. Two continents, Asia and Africa, are net importers of virtual water. They represent 46% of the imported virtual water. European Union occupies a specific place since it imports and exports high quantities of virtual water with a net balance almost equal to zero.

Table 3. Water consumed for crop production and virtual water traded from continents for year 1999, assuming an annual increase of 1% in water productivity. Values in km^3/year.

Continent	Water for crop production	Virtual water imported	Virtual water exported	Net virtual water balance	Virtual water balance/ water for food (%)
North and Central America	684	164	317	-153	-22
European Union	386	384	377	7	2
South America	445	52	175	-123	-28
Asia	1673	426	182	244	15
Oceania	71	8	117	-109	-154
Africa	241	97	19	78	32

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[1] Including the grasslands would result in a value close to 3 m^3/cap/day.

Table 4. Water consumed for crop production and virtual water traded from continents for year 1999, assuming an annual increase of 1% in water productivity. Values in m^3/cap/year except for (e).

Continent	Water for crop production (a)	Virtual Water imported (b)	Virtual water exported (c)	Net virtual water balance (d)=(b)-(c)	Consumption per day(1) (e)=(a)+(d)
North and Central America	1421	342	659	-317	3.0
European Union	1026	1020	1002	18	2.9
South America	1305	153	514	-361	2.6
Asia	436	118	50	68	1.4
Oceania	2345	281	3898	-3617	(2)
Africa	311	125	25	100	1.1

(1) This value excludes grass and other non cropped fodder products

(2) Value meaningless without considering grass and non cropped fodder products.

In terms of m^3/cap/year, the various data clearly show the inequality between continents although the figures here still neglect the use of grass and non crop fodder by cattle. North America and Europe use at least 3 m^3/cap/day of water to nourish their populations. South America is a bit lower with 2.6 m^3/cap/day. Asia and Africa lag behind with values respectively equal to 1.4 and 1.1m^3/cap/day respectively. Of course these values must still be corrected (in fact increased) but they clearly reveal already (1) the important needs of water for food and (2) the big inequalities between continents. If all continents would have adopted the same diet as the most developed countries, the total amount of water needed for the corresponding crop production would have been about 6 200km^3/year, i.e. a 74% more than the present situation. Most of this difference being due to Asia, it can be stated that Asia low water consumption for food production and the future evolutions of the diets of its inhabitants are very critical for the world water resources.

4.4. Comparison with other results

Hoekstra and Hung (2002) have computed virtual water values for crop products only, using a comparable method but actual crop yields per country obtained in FAO database in 1999 combined with country estimations of crop water requirements. Their values are therefore country-specific and likely more precise but they do not include virtual water linked to transformed and processed products. It is thus expected that differences with our valued are rather important for countries which export significant amounts of transformed products.

Results for the following countries were compared: Egypt, Ethiopia, Nigeria, India, Indonesia, Pakistan, China, France, Germany, UK, Russian Federation, USA, Mexico, Canada, Colombia, Brazil, Argentina, and Australia (see Table A3, Appendix). The average value of the period 1995-99 was taken from Hoekstra and Hung and compared with the values for 1999 obtained by Colin (with the assumption that water productivity increases by 1% per year).

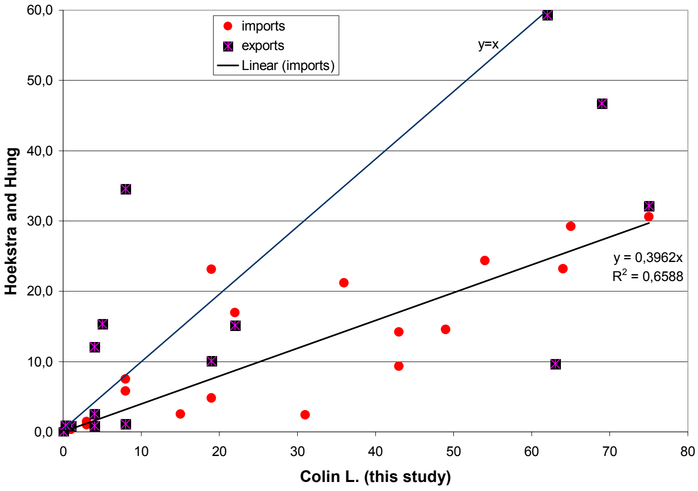

Figure 2. Comparison of imports and exports of virtual water by various countries from Colin (this study) and Hoekstra and Hung (2002).

As shown in the figure and as expected, a rather good correlation is obtained for imports and the values obtained in this study are significantly higher than those of Hoekstra and Hung. The average ratio is only 0.4 which is probably an indication that transformed and processed products represent a great part of the traded products. The latter has been confirmed by further simulations reported in Section 5.

For exports, as expected, the correlation is not good.

Oki *et al.* (2003) have also computed values of virtual water trade at global scale. They also used reference virtual water values split into two categories, namely one for exporting countries supposed to be low and one for importing countries supposed to be high. They provide figures at global scale of 1251 km^3/year for imports and of 866 km^3/year for exports. This again shows that the order of magnitude of virtual water trade is around 1 000 km^3/year.

Douglas (personal comm.) has computed water embedded in food products and traded virtual water for USA. As shown in the table below, the figures obtained from their computation compare very well with our results. But the references utilized in our study were mostly from USA!

Table 5. Water consumption in food products and virtual water exchanges for United States.

Results in km^3/yr	Colin (this study)	Douglas(1)
Total water consumption	502(2)	638(2)
Virtual water exports	234	229
Virtual water imports	65	40

(1) Personal communication.

(2) The figure given by Douglas includes grass production contrary to that by Colin.

5. Analysis of the global water for food budget

A second attempt to estimate water for food at global scale has been made considering the virtual values of all food products consumed at global level.

5.1. Principles

Food quantities required to sustain global food consumption has been estimated from FAO Balance sheets as follows:

- total production of each item from which we subtract stock changes, feed and others uses and multiply the results with values of virtual water as listed in tables A1 and A2 in Appendix.
- virtual water value of sea product and fish are included with an equivalence to animal product (5 m^3/kg).
- animals are considered as if they were all grown on feed lots (one way to account for grass and other sources of feed).

The resulting estimation of global water budget for food is expected to be much greater than the previous one which does not account for intermediate consumptions for animals and for sea food.

5.2. Global virtual water budget

Using references of specific water requirements for 1990 (see Appendix), the virtual water budget for food amounts to 5750 km3 for the year 2000. Considering an increase of water productivity of 1% per year (a very conservative assumption), the adjusting factor between 1990 and 2000 would be 0.904 and the estimated virtual water budget for 2000 establishes to **5200 km^3**.

5.3. Partition of virtual water per product

Out of the global budget, meat and animal products represent about 45% of the budget as shown in Figure 3, whereas cereals account for 24%, fish and sea food account for 8% and oil for 8%.

5.4. The importance of cereals for energy and protein

Cereals account for only 24 % of the global virtual water budget but contribute to more than half of the total food energy produced on earth as shown on Figure 4, and to almost- half of the protein budget (Figure 5). Wine and beer contributions to the energetic balance are important in some countries, of Europe in particular. However at global level, alcoholic beverages have a low contribution (1.6%) (Figure 4) to the trade of virtual water.

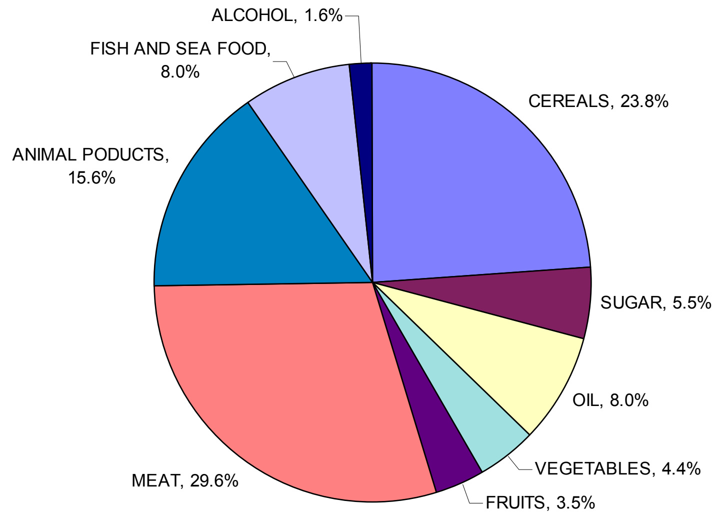

Figure 3. Distribution of global water embedded in food products in 2000 (5200 km^3).

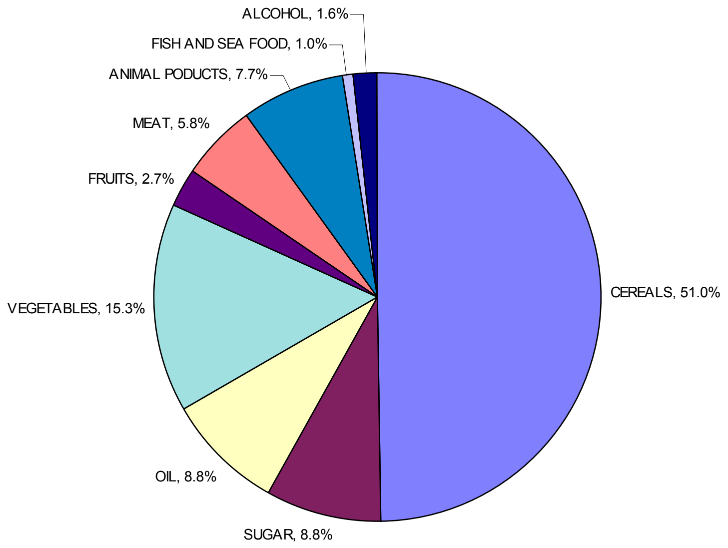

Figure 4. Partition of the global energy budget per food product.

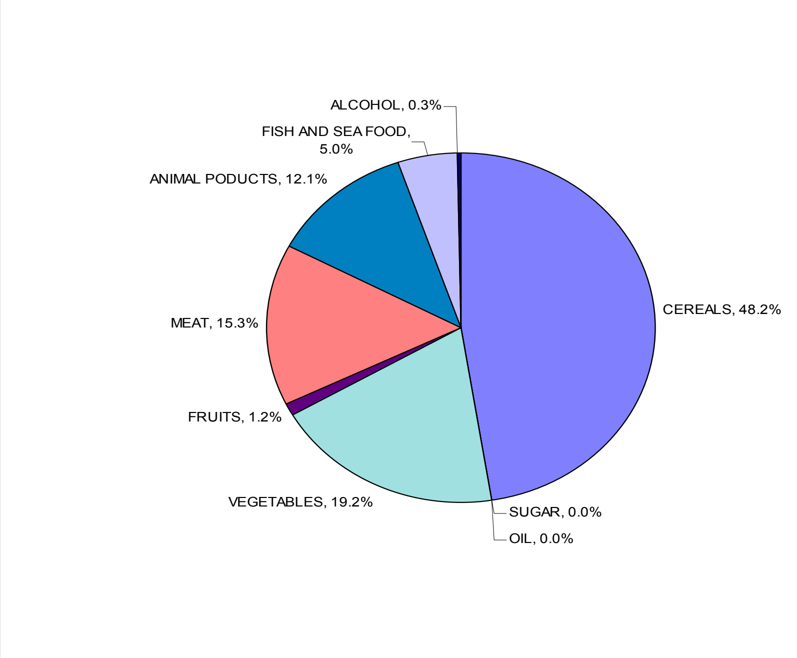

Figure 5. Partition of the global protein budget per food product.

6. Analysis of the global virtual water trade

6.1. Virtual water trade: one fourth of the global budget

The virtual water food trade amounts to 1485 km^3 for the year 2000 with references of virtual water values taken for 1990 (see Appendix). Assuming an increases in water productivity of 1% per year, the adjusted virtual water trade for 2000 is estimated at about **1340 km^3**. The difference with the results mentioned on Table 2 for virtual water trade (1100km^3) is due to the contribution of sea food and fish products.

This figure underlines again the importance of virtual water at global level. **Virtual water trade** in 2000 accounts for **one fourth of the global virtual water budget**, precisely 26%. This importance is likely to dramatically increase as projections show that food trade will increase rapidly: doubling for cereals and tripling for meat between 1993 and 2020 (Rosegrant and Ringler, 1999).

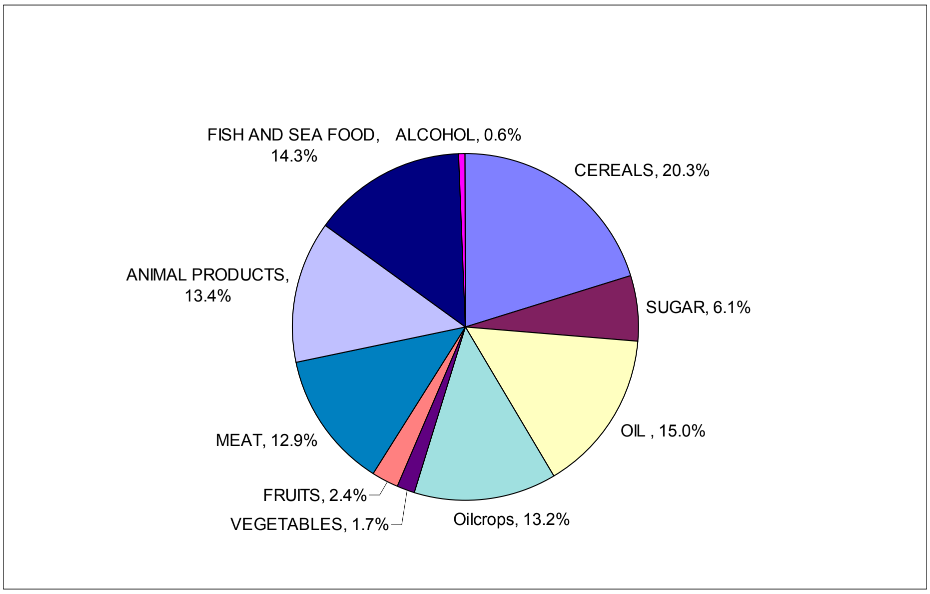

Figure 6. Global virtual water food trade in 2000 (1340 km^3).

It is important to note that part of vegetal products traded are for animal feed (some oil crops and cereals) or for processed products (some oil crops), therefore a fraction of the estimated virtual water trade is counted twice, as primary and transformed products.

6.2. Partition of virtual water trade per product

About 60 % of the virtual water trade is from vegetal products, the remaining 40% are shared almost equally by animal products, meat and fish + sea food. Cereals account for 20%, sugar for 6% and oil for 15% and oil crops for 13%.

Quite interesting and unexpected, cereals which have captured most of the attention in food security and virtual water studies, account only for 20 % of the total volume of virtual water exchanged. Of course when it comes to nutritional values, and for arid regions, the importance of cereals is much greater than one fifth. In 2000, cereals contributed to 40 % of the food energy trade as shown in figure 7.

6.3. Evolution with time of virtual water in food trade

The food trade has largely increased during the last decades. Figure 8 displays the historical evolution per main type of product. Vegetal products and sea products increase while animal products are more fluctuating. A decrease of animal products trade early 1090s followed a sharp increase during the 1980s. The political and economical changes and the meat crisis can certainly explain the decrease in early 1990s of the virtual water trade. Since 1995, we have retrieved the previous growth trend.

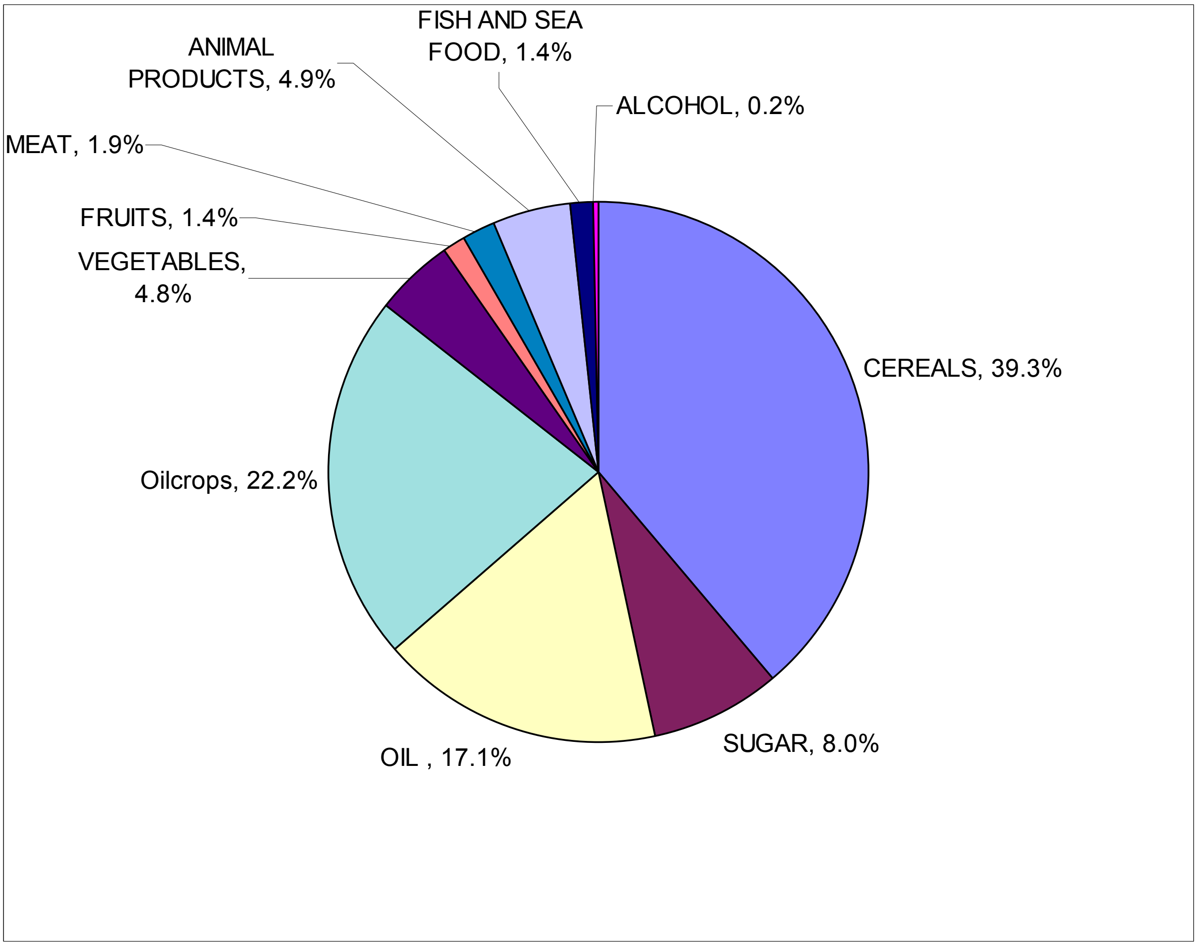

Figure 7. Partition of the global energy food trade per product.

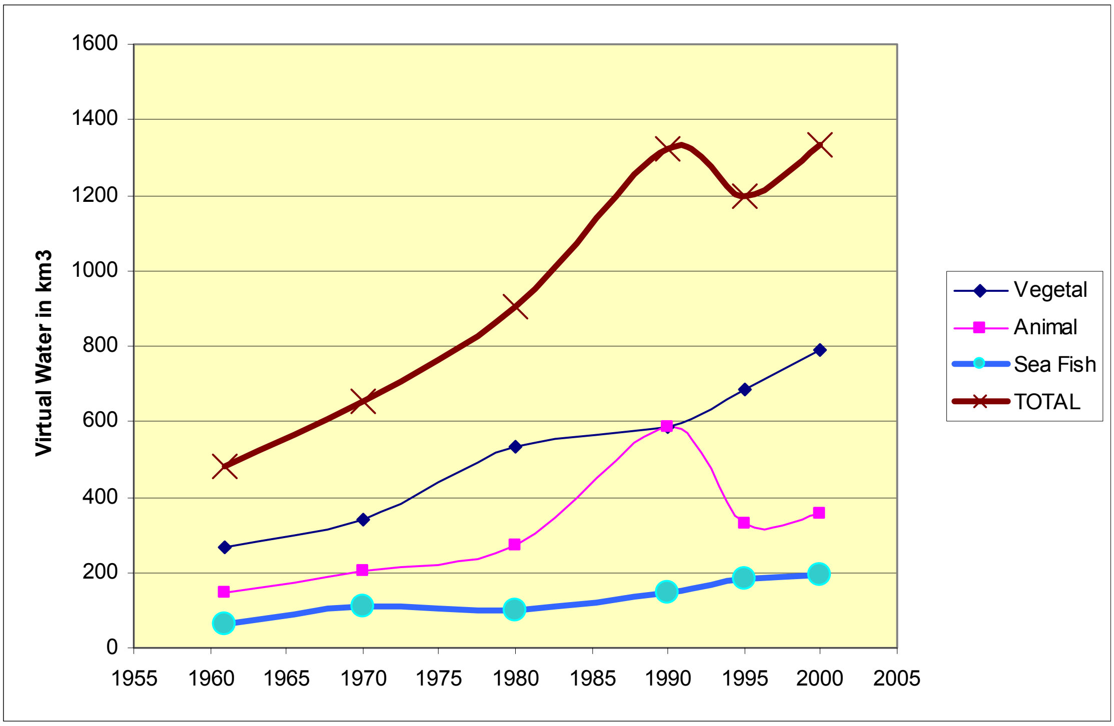

Figure 8. Virtual water in food trade between countries since 1961 considering an increase of water productivity of 1% per year.

6.4. Importance of trade per product

Some product are relatively more traded than others. In Figure 9 we plotted the ratio of quantity traded to quantity produced. We can distinguish three categories of products:

- The champions are oil, sea and fish products: about 45 % of the production is traded.
- The middle ones, from 17 to 28 %: cereals, sugar, oil crops, fruits and animal products
- The lower ones, at about 10 %: vegetables, meat and alcoholic beverages.

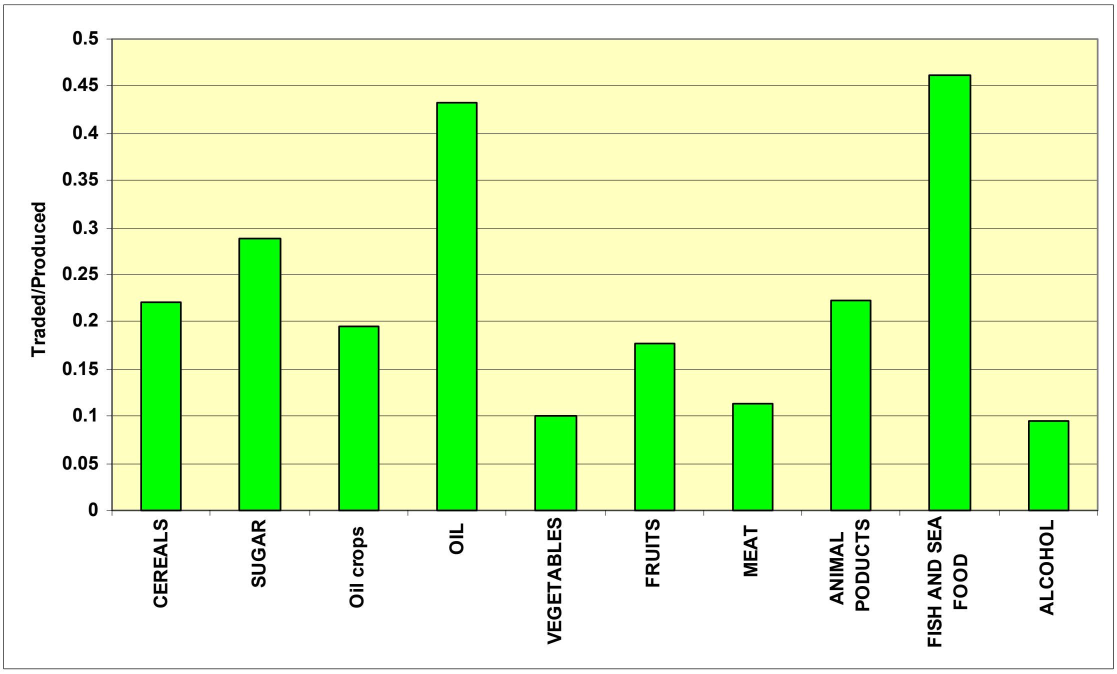

Figure 9. Trade rate per product in 2000.

7. Conclusions

The purpose of this paper was twofold: addressing methodological issues and providing preliminary results on global virtual trade. By doing so, our goal is to come up in the future with reliable and accurate methodologies for assessing virtual water. The practical objectives of this study is to map the virtual water budget at global level, in order to organize the next investigations phases with a pertinent framework. Preliminary results on virtual water budget at global level, and on virtual water trade give strong indications on where we should be focussing in the future to improve the accuracy of the assessment. For instance, alcoholic beverages are not enough important to be investigated in detail.

Regarding methodology, there are at least three important aspects that need to be properly addressed:

- Processes and products
- Mapping the fluxes
- Specifying the scope of the studies.

One of the main conclusions at this stage is that virtual water accounts in 2000 for one fourth of the global water budget for food, and it is likely that this ratio will increase in the future. This should be a strong motivation for launching more detailed studies on virtual water.

As expected cereal is the highest contributor to virtual water trade, but unexpectedly its share (20%) is not as high as would be expected from the attention given to virtual water related to cereals trade. Oil and oil crops trade is contributing to a high 28 % of the total. Meat and animal product contribute altogether to 26 %. Fish and sea food virtual water trade contribute to a significant 14 % of the total.

It remains of course important to disaggregate these values in order to have a better understanding of the virtual water streams per product and per regions. It is also important for future works to map the virtual water fluxes considering separately green and blue water.

Virtual water studies are still at a pioneer stage and this is the reason why it is important to compare studies made independently. Despite some variation in the results due to differences in the methods and the references considered, we found that the various assessments of virtual water made so far have provided quite similar values.

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Appendix

Table A1. Specific water demands of primary vegetal products. Values estimated for 1990.

Products	Specific water demand (m^3/t)	Country, Reference
Wheat, millet, rye	1159	California, Barthelemy et al.
Barley	1910	California, Barthelemy et al.
Oats	2374	California, Barthelemy et al.
Sorghum	542	Egypt, Barthelemy et al.
Rice	1408	California, Barthelemy et al.
Maize	710	California, Barthelemy et al.
Cereals, others	1159	California, Barthelemy et al.
Potatoes	105	California, Barthelemy et al.
Sugar beet	193	California, Barthelemy et al.
Sugar Cane	318	California, Barthelemy et al.
Pulses	1754	Egypt, Barthelemy et al., TS and FAO databases
Tree nuts	4936	Tunisia, Barthelemy et al.
Groundnuts	2547	California, Barthelemy et al.
Rape and Mustard seed	1521	Germany, BRL data base
Soybeans	2752	Egypt, Barthelemy et al.
Olives	2500	Tunisia, Barthelemy et al.
Sunflower	3283	Egypt, Barthelemy et al., TS database
Tomatoes	130	California, Barthelemy et al.
Onions	168	California, Barthelemy et al.
Vegetable, others	195	California, Barthelemy et al.
Grapefruit	286	California, Barthelemy et al.
Lemons, limes	344	California, Barthelemy et al.
Oranges and other citrus	378	California, Barthelemy et al.
Bananas	499	California, Barthelemy et al.
Apples	387	California, Barthelemy et al.
Pineapples	418	California, Barthelemy et al.
Dates	1660	California, Barthelemy et al.
Grapes	455	California, Barthelemy et al.
Fruit, others	455	California, Barthelemy et al.

Table A2. Specific water demands of transformed or processed products. Values estimated for 1990.

Products	Specific water demand (m^3/t)	Country, Reference
Cottonseed	1145	California, TS and FAO databases
Coconut oil	5500	Substitution(1)
Palm oil	5500	Malaysia, Indonesia, TS Database
Palmkernel oil	5500	Substitution(1)
Sesame seed oil	5500	Substitution(1)
Groundnut oil	8713	California, Barthelemy et al.
Sunflower seed oil	7550	California, Barthelemy et al.
Rape and Mustard oil	3500	Germany, BRL data base
Soybean oil	5405	Egypt, Barthelemy et al., TS and FAO databases
Cottonseed oil	5500	California, TS and FAO databases, substitution(1)
Olive oil	11350	Tunisia, Barthelemy et al.
Bovine, mutton, goat meat	13500	California, Barthelemy et al.
Pig meat	4600(2)	California, Barthelemy et al.
Poultry meat	4100	California, Barthelemy et al.
Other meat	13500	California, Barthelemy et al.
Eggs	2700	California, Barthelemy et al.
Milk	790	California, Barthelemy et al.
Butter + Fat	18000	California, Barthelemy et al.
Sugar	1929	California, Barthelemy et al., TS database
Sweeteners	2731	California, Barthelemy et al., TS database

(1) no values found, substitution with palm oil value which is the most traded oil utilised

(2) value to be debated in countries where pork is fed mainly with waste products

Table A3. Water consumed for crop production and virtual water traded from various countries for year 1999, assuming an annual increase of 1% in water productivity. Values in km^3/year.

Country	Water for crop production	Virtual water imported	Virtual water exported	Net virtual water balance	Virtual water balance/ water for food (%)
Argentina	114	3	69	-66	-58
Australia	64	3	85	-82	-128
Brazil	251	19	75	-57	23
Canada	93	19	62	-43	-46
China	624	75	19	56	9
Colombia	23	8	4	4	17
Egypt	32	22	1	21	65
Ethiopia	11	1	0.04	1	9
France	103	43	91	-48	-47
Germany	75	64	63	1	1
India	423	31	8	23	5
Indonesia	422	36	8	27	6
Mexico	47	54	5	49	104
Nigeria	47	8	0.3	7	15
Pakistan	56	15	4	11	20
Russian Federation	93	49	4	45	48
UK	35	43	22	21	60
USA	502	65	234	-169	-34

6

A water resources threshold and its implications for food security

H. Yang, P. Reichert, K.C. Abbaspour and A. J. B. Zehnder

Cereal import has played a crucial role in compensating local water deficit. A quantitative articulation of water deficit and cereal import relations, therefore, is of significance for predicting future food import demand and formulating corresponding national and international policies. Based on data for countries in Asia and Africa, we estimated a water resources threshold with respect to cereal import of 1500 m^3/(capita year). Below the threshold, the demand for cereal import increases exponentially with decreasing water resources. Until the end of the twentieth century, many countries below the threshold were oil rich and thus were able to afford cereal import. However, the next 30 years will see many poor and populous countries dropping below the water resources threshold in association with their rapid population growth. Water deficit-induced food insecurity and starvation could intensify because cereal import may not be affordable for these countries.

On the world average, agriculture uses about 70% of the total water withdrawals (*1*), making it, by far, the largest water user. This leads to an intrinsic relationship between a country's renewable water resources and the capacity for food production. In water scarce countries, an increasing amount of food has to be imported to substitute local water demand for food production. Of the food imported, cereal grains have been the dominant commodities in terms of the quantity and importance for food security to the importing countries. The water that is required for producing the imported food is termed "virtual water" (*2*). Cereal grains have been the major carrier of virtual water, and the import has played a crucial role in compensating water in the countries where the resource is scarce (*3*).

Despite the increasing awareness of the constraints of water scarcity on food production and the importance of food import for compensating water deficit, to the best of our knowledge, no study has so far modeled the water deficit and food import relations. With the aggravation of water scarcity in many countries and regions in the world and a growing number of the population experiencing water stress (*1*), the need for a quantitative articulation of such relations becomes prominent. The modeling result can help project the scale of the demand for food import that is induced by water deficit in the coming years. The information can also be useful to national policy makers and international food agencies for stipulating policies to meet the challenges ahead.

Against this backdrop, we identify a threshold of water resources with respect to cereal import using country-level statistical data. Based on this threshold, we project the potential scale of water deficit-induced cereal import in the next 30 years and address its implications for food security.

Following the common convention, the renewable freshwater resources of a country are defined as the sum of the mean annual surface runoff and groundwater recharge expressed on a per capita basis (*1, 4, 5*). Because cereal production and import fluctuated significantly from year to year due to variations in weather and market conditions, five-year running averages were calculated for the data from 1980 to 1999. This resulted in 16 partially overlapping data periods. The investigation focuses on countries in Asia and Africa (*6*) with more than 1 million inhabitants (*7*) and available water resources less than 5000 m^3/capita per year (*8*). All the data used for the analysis are from the World Resources Institute (*9*), Food and Agricultural Organization of the United Nations (FAO) (*10*) and the World Bank (*11*).

The investigation starts by analyzing the net cereal import as a function of renewable water resources (abbreviated “Water”) alone. A parameterized model is defined by the following exponential function:

$$\text{Net cereal import} = a + b \exp(-3/c \text{ Water}) \quad (1)$$

where a represents the base net cereal import independent of water resources, b is the theoretical maximum amount of net cereal import as water approaches zero, and c is the renewable water resources below which a significant correlation exists between net cereal import and water resources at the country level (*12*). We define *c* as the threshold of water resources, and countries with water resources below the threshold as water deficient countries. To support the identification of the parameterization of model (1), a non-parametric regression is also conducted.

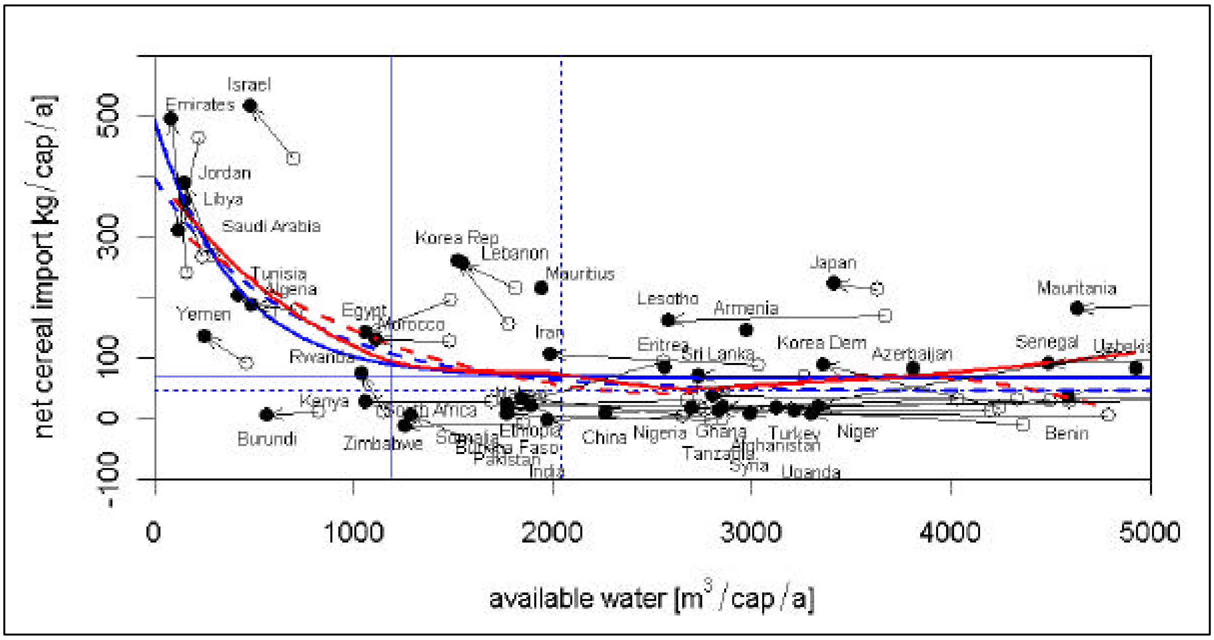

Figure 1. Fits of model (1) for the first (1980-1984; thick dashed blue line and open circles) and the last (1994-1999; thick solid blue line and filled circles with country names) investigation periods. Arrows in the diagram indicate movements of the positions of the countries from the first to the last period. The positions of the parameters a and c of the model are indicated by horizontal and vertical thin lines, respectively (dashed for the first, solid for the last period). A fit of the non-parametric model (loess with span=0.75)(13) shows that the parametric model is adequate (thin dashed and solid red lines, respectively). A Monte Carlo analysis suggests that the model results are insensitive to the cut-off value of 5000 m^3/cap/a.

The fits of model (1) to the data for the first (1980-1984) and the last (1995-1999) investigation periods are in close agreement with the non-parametric regression (Figure. 1). This demonstrates that model (1) is a reasonable parameterization for describing the cereal import as a function of available water only. The R^2 value of around 0.45 suggests that the model explained about half of the variation in net cereal import. The dependence of parameter *c* on only a small number of the data points, however, leads to a rather high uncertainty of this parameter. Nevertheless, a *t*-test indicates that parameter *c* is significantly different from zero at the 95% confidence level for the last 5 periods when more countries fall below the threshold (*14*).

Between the two investigation periods, there is a significant decrease in per capita renewable water resources for all the countries considered (all arrows point to the left), a result of population growth. In almost all the countries with water resources below the threshold, there is an increase in per capita cereal import (arrows point upwards) (*15*). In contrast, per capita cereal import remained mostly unchanged in the countries with water resources above the threshold, suggesting no significant relationship between changes in their per capita water resources and the volume of cereal import.

Although the general trend in cereal import is relatively well represented by model (1), there is a considerable amount of variation in the net cereal import per capita for countries with similar water resources. For example, the net annual cereal import in Burundi is almost negligible despite its meager water resources. In contrast, with the similar level of water resources the volume of import in Algeria, Egypt and Morocco all exceeded 120 kg/capita/annum. This situation gives rise to a consideration of other factors in the model. To identify such additional factors, correlation coefficients are calculated between the residuals of model (1) and potential influence variables depicting a country's physical, technological, and socio-economic conditions (Table 1) (*16*).

Table 1. Correlation matrix of the residuals of model (1) with potential influence factors for the last investigation period (1995-1999).

	Residuals	Water	Land	Irrigation	Fertilizer	log(GDP)
Residuals	1	-0.09	-0.37	0.06	0.32	0.58
Water	-0.09	1	0.25	-0.18	-0.10	-0.38
Land	-0.37	0.25	1	0.07	-0.08	-0.08
Irrigation	0.06	-0.18	0.07	1	0.54	0.50
Fertilizer	0.32	-0.10	-0.08	0.54	1	0.62
log(GDP)	0.58	-0.38	-0.08	0.50	0.62	1

Water = renewable annual freshwater per capita (m^3/a); Land = sum of arable land and permanent cropland per capita (ha); Irrigation = irrigated area per capita (ha); Fertilizer = fertilizer application per capita (ton/a); GDP = gross domestic product per capita (US$).

The small correlation coefficient between the residuals and “Water” indicates that model (1) describes the dependence of net cereal import on freshwater resources. The correlation coefficient of 0.58 identifies log(GDP) as the most important potential influence factor for cereal import (*17*). Inclusion of log(GDP) in the model yielded model (2).

$$\text{Net cereal import} = a + b\exp(-3/c\ \text{Water}) + d\log(\text{GDP}) \qquad (2)$$

With a R^2 value of about 0.65, model (2) is a significant improvement over model (1) in explaining the variation in cereal import. This is confirmed by an F test for comparing nested models (the P-value is higher than 99%). A *t*-test indicates that parameter *d* is significantly different from zero at the 99% confidence level for all investigation periods.

Noting that "Land" has the second largest correlation coefficient after log(GDP) (Table 1), we included the variable “Land” in the model and obtained:

$$\text{Net cereal import} = a + b\exp(-3/c\ \text{Water}) + d\log(\text{GDP}) + e\ \text{Land} \qquad (3)$$

The improvement of model (3) over model (2) is marginal. R^2 increased only by 0.3 and an F test for nested models revealed only a significant improvement of this model at the 95% confidence level over model (2) for the last four investigation periods. A *t*-test of parameter *e* shows a similar result.

We did not go further to include "Fertilizer" and "Irrigation" in the model simulations because of their high correlation with log(GDP) and the small correlation with the residuals of model (1), especially for “Irrigation” (Table 1).

To compare the results of models (1), (2) and (3) and observe the trend of changes over the years, the values of parameters *a*, *b*, *c*, *d*, and *e* for the 16 investigated periods with their associated uncertainty bands are plotted (Figure 2).

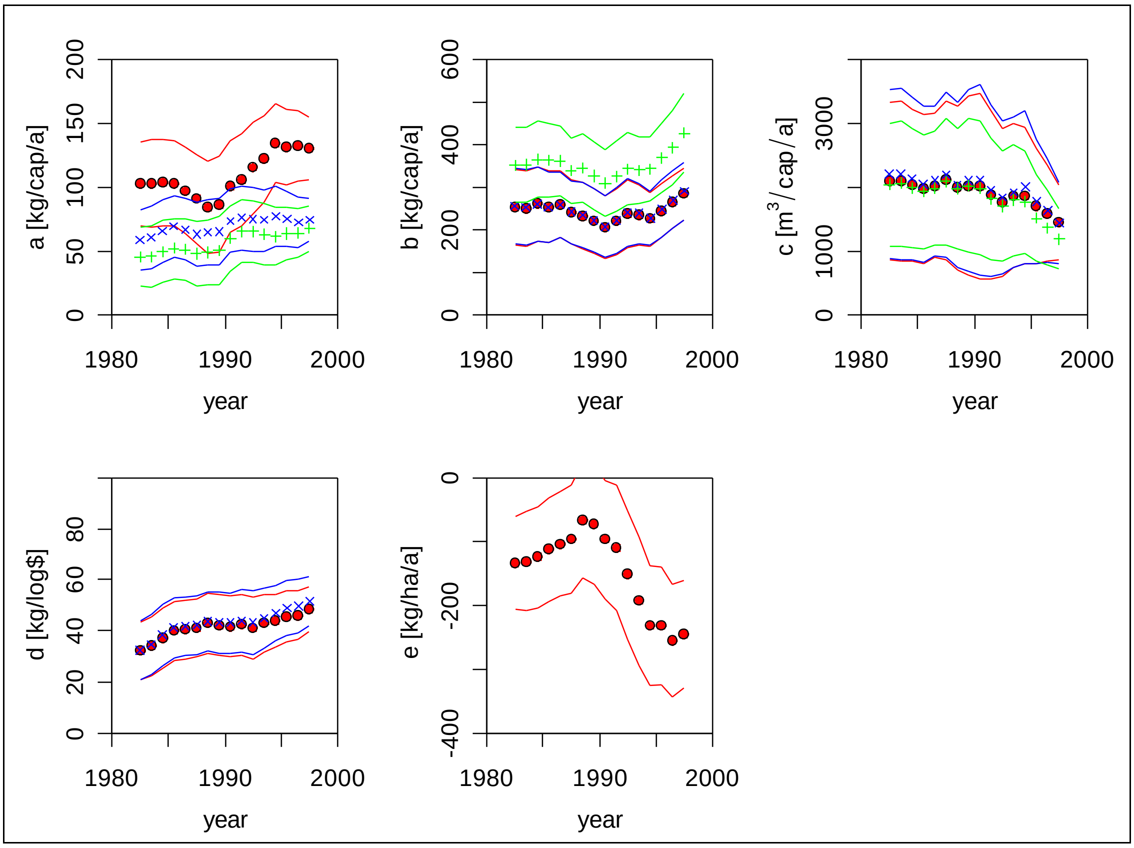

Figure 2. Estimated parameters with uncertainty bands for the three parametric models (the solid lines indicate estimates plus and minus one standard error). Green symbols and uncertainty bands indicate parameter estimates of model (1), blue symbols and uncertainty bands those of model (2), and red symbols and uncertainty bands those of model (3).

The inclusion of additional variables in models (2) and (3) led to upward shifts in parameter *a* in comparison to model (1) (Figure 2). While the shifts may have no intrinsic meaning, the rising trend of *a* since the late 1980s is noteworthy. It suggests that the countries included in the analysis overall tended to import a larger amount of cereal on per capita basis in the later years than in the earlier years. This trend may partly be attributable to the decline in cereal prices. Between 1980 and 1999, average cereal prices at the international market dropped by some 25 percent in current US dollar terms. Taking into account a roughly 50 percent depreciation of the dollar during this period, the price drop had been substantial. This would have made cereal import both more affordable and economically efficient to all the countries concerned, resulting in a rise in parameter *a*.

Parameter *b* shifts downward by the inclusion of log(GDP). This may be because in model (1) it captured some of the contributions of GDP to the increase in cereal import.

The positive value for the coefficient *d* is an expected result as a high GDP allows a country to purchase the amount of cereal that cannot be met by domestic production. Meanwhile, a higher income also leads to a greater cereal demand in association with a larger portion of meat and other animal products in the diet. Conversely, poor countries have a low affordability for cereal import. Taking Burundi as an example, the negligible cereal import is in direct relation to its very low GDP per capita, below US$140. The average calorie intake in the country is only 1628 kilo-calories/(capita day), substantially below the minimum dietary energy requirement of 2500 kilo-calories/(capita day) (*18*). Thus, the message that could be drawn here is that while water deficit presents a rigid constraint to food production; food insecurity and starvation are rather a direct result of low incomes.

The negative sign of parameter *e* reflects the inverse relationship between availability of land resources and cereal import. The declining trend may be related to the improvement in land productivity over the years, represented by the increase in crop yields.

The water threshold, *c*, in which we have a special interest, is very stable from one model structure to the other. This increases the confidence in its value. The uncertainty band of the estimate also narrowed in the later years with more countries falling below the threshold (Fig. 2).

Thus far, our model simulations demonstrate that a water resources threshold can be defined. Below the threshold, a country's cereal import is strongly related to the renewable water resources. Above it, no direct relationship is discernable. At the end of the 1990s, the estimated threshold of water resources stood at approximately 1500 m^3/(capita year) (Fig. 2), which was close to the water stress threshold of 1700 m^3/(capita year) suggested by Falkenmark and Widstrand (*5*) and cited widely in the literature.

There appears to be a declining trend in the threshold, *c*, during the period studied. The improvement in water use efficiency (defined as more crop per drop) and the expansion in irrigated areas (increased ability to tap water for agricultural uses) may have partly contributed to this decline. A point that must draw attention here, however, is the exclusion of non-renewable groundwater from the estimation of the threshold. The extraction of non-renewable groundwater has become massive in many water scarce countries and regions during the last two decades, causing a depletion of aquifers at an alarming rate. In our model simulations, however, the use of non-renewable groundwater was not taken into account because of the lack of systematic data. This led to a downward distortion of the constraint of renewable water resources deficit on food production and the demand for cereal import. In other words, the parameter *c* underestimated the real threshold to some degree. For this reason, and because of the high uncertainty of the fitting result, the magnitude of the decline in the estimated threshold, *c,* should be viewed with caution.

Table 2. List of the countries in Africa and Asia having renewable freshwater resources below the calculated threshold of 1500 m^3/capita by the year 2030. Bold names are the countries entering the list after the year 2000.

Afghanistan	Egypt	Kenya	**Niger**	**Tanzania**
Algeria	**Eritrea**	Korea Rep.	**Nigeria**	**Togo**
Burkina Faso	**Ethiopia**	Lebanon	**Pakistan**	Tunisia
Burundi	**India**	Libya	Rwanda	**Uganda**
Cape Verde	**Iran**	**Malawi**	Saudi Arabia	Emirates
Comoros	Israel	Maldives	**Somalia**	Yemen
Cyprus	Jordan	Morocco	South Africa	Zimbabwe

Using population prediction figures and the associated uncertainties expressed as low and high variants from the United Nations (*19*), we calculated the per capita renewable water resources of the countries considered in this study up to the year 2030. Subsequently, the total annual water deficit of the countries with water resources below the threshold of 1500 m^3/capita was calculated. Such a deficit is defined as the difference between the threshold and the per capita renewable water resources multiplied by the population of the country and summed over all countries below the threshold. The result shows that the total expected water deficit of the countries considered (Table 2) in the year 2030 is around 1150 km^3, a volume roughly 10 times the annual discharge of the Nile River (accounting for the population uncertainties: low variant = 800 km^3 and high variant = 1500 km^3) (Fig. 3a). Using model (1) and the parameters *b*, and *c*, obtained for the period (1995-1999), we calculated the potential demand of cereal import induced by water deficit with the associated uncertainties (Fig. 3b). The volume stands at a staggering amount of 140 million tons by the year 2030 (low variant = 120 million tons and high variant = 160 million tons) compared to 30 million tons in 2000. The total cereal supply at the international market would have to increase by 50 percent from the current volume of some 200 million tons to just cope with this additional need in the countries studied. Adding the demand from countries that may drop below the threshold in the coming years in other continents, water deficit-induced cereal import will be even greater.

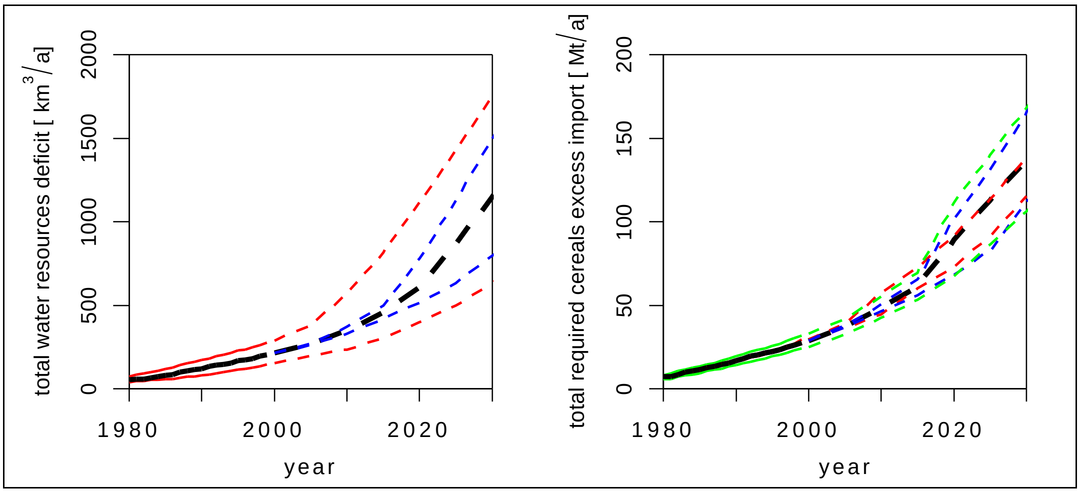

Figure 3. a) Projection of total water deficit of the countries with renewable freshwater resources below the threshold of 1500 m^3/capita (expected values in black, high and low UN population forecast variants in blue, and expected values for water thresholds of 1300 m^3/capita and 1700 m^3/capita in red). b) Projection of the expected "water deficit induced" cereal import calculated with model (1) [i.e., bexp(-3/c Water)] (black) with uncertainty bands in association to the high and low UN population forecasts (blue), water threshold values of 1300 m^3/capita and 1700 m^3/capita (red), and uncertainty in the model parameters (green).

Until the end of the 1990s, most of the countries with water resources below the threshold have been oil rich and/or had the GDP above the low-income level in the World Bank income classification. The ability to purchase food from the international market had enabled these countries to compensate their water deficit and to meet the domestic demand (Fig. 1). Looking ahead, however, the situation can become increasingly worrisome. Many countries that will fall below the water resources threshold are poor and hence are unable to afford the purchase of cereals. Compounding the situation is an expected increase in cereal prices in response to the overall greater demand. Given the large population sizes of some of the newly added poor countries, the scale and incidence of food insecurity could become much higher in the coming years than what has been seen in the past.

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3. H. Yang and J. B. Zehnder, *World Development*, **30**, forthcoming (2002).

4. C. Vörösmarty, P. Green and J. Salisbury, *Science* **289**, 284 (2000).

5. M. Falkenmark and C. Widstrand, *Population Bulletin* **47**(3), 1 (1992).

6. Most of the countries with large net cereal import and small amount of water resources reside in Africa and Asia. The two continents are also home to a majority of the people living under constant food insecurity. In contrast, except for four countries in temperate Europe and a number of small island states, all the countries outside Asia and Africa have water resources over 2200 m^3/capita per year, excluding them from the water scarce country list in any existing classification.

7. This is to reduce the effect of specific local conditions in small countries on the analysis of the general relationship between water deficit and cereal import.

8. This guarantees that the water scarce countries are considered in the analysis while allowing a comparison with water sufficient countries.

9. World Resources Institute, *Environmental Data Tables* (On-line Database, www.wri.org) (2002).

10. FAO, *FAOSTAT* (On-line Database, www.fao.org) (2002).

11. World Bank, *World Development Indicators* (CD-Rom) (2000).

12. The exponential relationship between cereal import and available water resources allows some freedom in defining a threshold value. The factor 3 in the exponent of model (1) defines the parameter c as the amount of available water at which the excess cereal import (exceeding the base level a) decreases from its maximum value of b to 5% of b.

13. W. Cleveland, E. Grosse, and W. Shyu, in *Statistical Models* in S, J. Chambers and T. Hastie, Eds (Wadsworth & Brooks/Cole, California, 1992).

14. A bootstrap test, however, indicates that the t-test is rather conservative with respect to the lower confidence limit but too optimistic with respect to the upper limit.

15. Saudi Arabia and Egypt are two prominent exceptions. Cereal production in Saudi Arabia increased from barely 0.3 million ton in the early 1980s to a peak of over 5 million tons in the early 1990s. The expansion of irrigation by extracting nonrenewable fossil groundwater contributed largely to this increase. Since then, the production dropped and stood at around 2.6 million tons at the end of the 1990s. This reverse trend, however, is not reflected in Fig. 1 where only the import volumes of the first and the last periods are presented. Egypt has a 100 percent irrigation coverage and irrigated areas expanded by 35 percent during the period observed. This has been the foundation underlying a relatively rapid growth in its cereal production, resulting in a decrease in cereal import on per capita basis while the total volume of the import continued to increase. However, given the increasing water constraints, it is unlikely for the country to keep up this growth rate in the coming years. The portion of cereal import in total supply is expected to increase sooner or later.

16. The choice of the variables was based on what are commonly used and also their availability. Cereal prices were not considered as an independent variable because all countries face the same prices at the international market. The influence of cereal prices on import is thus reflected in parameter a of our cross sectional model.

17. We used the log of GDP in order to satisfy the assumption of constant error variance.

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7

Virtual water trade in global governance

K. Mori

1. Introduction

Tony Allan's concept of virtual water was originally intended for peaceful trading of the water embedded in water-intensive commodities for water-deficit countries. However, as Sandra Postel and others point out, there exist some conditions for successful virtual water trade that would lead to peace in today's complex international political economy.[1] Unless a set of norms, principles, rules, and decision-making systems are carefully designed and successfully converged upon, it would lead to even more conflicting situations in the rapidly changing global trading system. Unlike real water trade, a successful virtual water trading system would work as a virtual currency in a like-minded community, with sharing of the norms and principles of integrated water resources management and governance.

In terms of good governance on water resources management, at least three main values have been identified in accordance with the three pillars of sustainable development: social, economic, and environmental dimensions. The 1975 United Nations Water Conference held in Mar del Plata gave priority to the basic human needs of safe drinking water and sanitation services. The principles adopted at the 1992 International Conference on Water and the Environment included fresh water as a finite and vulnerable resource; and water as an economic good. The *World Water Vision* named water for nature in two ways: "blue water" – renewable surface water runoff and groundwater recharge, and "green water" – the rainfall that is stored in the soil and evaporates from it. The concept of virtual water trade is based primarily on the Dublin Principles, and yet it also has to integrate social and environmental values of water adequately.[2]

If these values are successfully embedded in the virtual water trading system, the system can be a useful tool for reconstructing today's global governance on sustainable development. In particular, it can bridge the existing gaps between international regimes on trade and the environment. The Johannesburg Summit's *Plan of Implementation* agrees to "promote mutual supportiveness between the multilateral trading system and the multilateral environmental agreements, consistent with sustainable development goals, in support of the work program agreed through WTO, while recognizing the importance of maintaining the integrity of both sets of instruments".[3] The paper discusses the relevance of the virtual water trade concept in the context of the World Trade Organization (WTO) and some of the multilateral environmental agreements (MEAs).

2. Virtual water in the WTO contexts

Unlike the General Agreement on Tariffs and Trade (GATT) 1947, the preamble of the 1994 Marrakech agreement establishing the WTO mentions the objective of sustainable development, and the WTO Committee on Trade and Environment (CTE) was established. The CTE has discussed ten items, including trade rules and MEAs. Virtual water trade can be discussed in many aspects of the currently negotiating WTO work program that was chosen for launching at the Doha Ministerial 2001. This section will focus on two agenda items of the seven negotiation groups set up by the WTO Trade Negotiations Committee: (1) agriculture and (2) trade and environment.

2.1. Agriculture

Since agriculture is the largest economic sector using water resources at the global level, trade in agricultural products is the main component of trade in virtual water. The WTO agricultural negotiations started in early

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[1] Postel argues that virtual water trade will be unstable when an increased number of water-short countries go beyond Falkenmark's net precipitation per person drops of 1,700 cubic meters due to increased population. Sandra Postel, *Pillar of Sand* (N. Y.: W.W. Norton, 1999), p. 129.

[2] World Water Council, *World Water Vision* (World Water Council, 2000).

[3] *Plan of Implementation*, Paragraph 91.

2000 under Article 20 of the Agreement on Agriculture to establish "a fair and market-oriented trading system through a program of fundamental reform," and a large number of negotiating proposals have been submitted and discussed. "Modalities" for the negotiations will be established by the end of March 2003, and based on these modalities, members are expected to submit comprehensive draft schedules by the Cancun Ministerial in 2003. The main negotiating agenda includes (1) substantial improvements in market access; (2) reductions of export subsidies; and (3) reductions in trade-distorting domestic support.

The concept of market access is based on a combination of free and fair trade norms. A minimum access, which was determined by inter-governmental negotiations, can be regarded as a kind of managed, rather than liberal, trade. Yet, it was justified as an affirmative action for a fair and market-oriented trading system. The Uruguay Round agreement on agriculture included the principles of comprehensive tariffication and minimum access. With the former principle, non-tariff barriers, such as import quotas, are to be converted to tariffs, and these tariffs were then to be reduced by 36 percent for developed countries (24 percent for developing countries) on average for all agricultural products, with a minimum reduction of 15 percent for developed countries (10 percent for developing countries) required for each product. The latter principle requires that a minimum access equal 3 percent of domestic consumption be established initially, and that the minimum access should increase up to 5 percent over the six years of the agreement.

In renewing the market access regime, member countries can take account of water balance in terms of international trade of water-intensive agricultural products. Food self-sufficiency targets, maintained by many countries for security and other purposes, may relax with a fair and reliable trading system. To maintain fairness, market access to exporting countries of agricultural products should be significantly reduced. It will also be important to correct increasing importation of water-intensive products from countries with poorly managed water resources. Tariff levels and minimum access for water-intensive products may also be determined by taking account of yearly and seasonal fluctuations of water resources availability.

Large export subsidies for agricultural products of OECD countries, especially the EU members, are regarded as a major obstacle for sustainable development in developing countries. From the perspective of developing countries, a combination of import liberalization without removing or reducing export subsidies of developed countries has a serious damaging effect on their farming sectors, many of which are also conditionally financed by structural adjustment loans from the Bretton Woods institutions. Therefore, virtual water trade should not be utilized as a political tool to justify export subsidies for water-intensive agricultural products from developed economies.

Subsidies for the agricultural sector have been provided for not only exportation but also domestic policy purposes. Under the Uruguay Round agreement, all forms of domestic support were categorized into three groupings based on their effects on production and trade. The three categories are called the amber box, the blue box and the green box. The amber box programs are considered to be the most trade distorting and as "proceed with caution," because they are directly linked to production or price supports they must be reduced by 36 percent within six years of the agreement.

Environment-related programs are normally placed in the green box category, which are exempted from reduction commitments ("exempt measures"). What about domestic support for virtual water trade? The Friends of Multi-functionality (European Union, Norway, Japan, South Korea, Switzerland, and Mauritius), which emphasize the multiple functions of agriculture in preserving the environment and protecting rural communities, may add the virtual water concept as another function. The rationale can be that the value of water embedded in a product is not properly recognized and reflected in trading prices for agricultural commodities, and therefore that subsidies and other forms of domestic support are justified. From the perspective of the Cairns Group of agricultural exporting countries, it will be regarded as a new form of protectionism. Therefore, it is necessary to agree on whether or not domestic protection measures for virtual water trade can be put in the green box category.

2.2. Impacts of trade liberalization on the environment

It is usually believed that the "tragedy of commons," state failures, and/or market failures, rather than international trade itself, leads to environmental degradation. According to Garret Hardin's explanation of the tragedy of commons, the natural resources as common commodities are overexploited due to the ill-defined property rights of commons.[4] The main strategies to escape from the tragedy of the commons are strengthened

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[4] Garret Hardin, "The Tragedy of the Commons," *Science*, 162 (1968).

private or public property rights. Another strategy proposed more recently is a public-private partnership. Natural resource utilization will be unsustainable whenever these strategies are not successfully implemented.

Thus, theoretically, the impact of trade liberalization on the environment may be positive or negative. This section will examine possible impacts on the environment made by (1) transboundary movement of agricultural products, (2) expanded market size for agricultural products, and (3) the changing international division of labour in the farming sector.[5]

The positive impact of international trade and transboundary movement (i.e., virtual water "aid" and "investment" to be included) of agricultural products on the environment includes transfer of environmentally sound technology. For example, the introduction of the New Rice for Africa (NERICA), which is a hybrid rice strain, resistant to local drying stresses, is expected to produce higher yields with, or even without, using fertilizer. A possible negative consequence of the introduction of alien species is that they are potentially harmful to local ecosystems. In particular, the extent to which genetically modified organisms (GMO) (most of which are currently produced in and exported from the United States, Canada, and Argentina) impact on the environment is not fully known. The WTO Sanitary and Phytosanitary (SPS) agreement requires scientific evidence for food safety and animal and plant health measures. The international scientific communities involved in identifying safety should inspect water-saving GMO products.

Scale of economy expanded by international trade in water-embedded products can have positive impacts on environmental and other policy objectives. For instance, increased efficiency in distribution of water resources can generate new and additional funds. Those funds may be especially useful to recently decreased financial resources for much needed water-related infrastructure development. On the other hand, the scale of economy with increased efficiency in water resources may lead to fast overexploitation of water resources beyond acceptable environmental limits at the global level. Although water is a renewable resource, virtual water should also reflect the quality of water resources management because an increase in degraded water limits the availability of safe water resources. The rapidly expanding global market should also be accompanied by a rapid correction of unsustainable, demand-side consumption management at the global level.

Shifts in the international division of labour, based on comparative advantages of available water resources and other factors, will have positive impacts at the local level also. If water-short countries can stably import water-intensive products from overseas, scarce water resources there can be used effectively for basic human and other needs. However, it would limit a variety of options for economic development in both water-short and water-rich countries. If production and consumption of water-embedded products are not distributed in a sustainable manner, specialization and concentration of specific products in specific areas will be promoted further. Possible negative effects of further specialization on water-intensive production include overexploitation of water resources at the local level, and even a water-rich country may be degraded into a water-short country in the near future.

3. Impacts of MEAs on virtual water trade

Among many multilateral agreements related to water resources, a possible main agreement directly related to virtual water is the UN Convention on the Law of the Non-Navigational Uses of International Watercourses adopted in 1997. However, the Watercourse Convention has not yet entered into force, because the required number of ratifications was not collected by the prescribed date. This section discusses possible impacts of three other MEAs on virtual water trade: the UN Convention to Combat Desertification (UNCCD) adopted in 1994, the Convention on Biological Diversity (CBD) adopted in 1992, and the UN Framework Convention on Climate Change (UNFCCC) adopted in 1992.

Environmental policies based on MEAs can have effects that facilitate as well as limit international trade in virtual water. Environmental policies adopted and implemented by state and non-state actors can be classified by varying degree and form: from strong regulation by the government sector to voluntary actions made by non-state actors.[6] A mixture of regulatory framework and market-based or voluntary measures is also available.

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[5] Ministry of the Environment, Japan. *Report on Trade Liberalization and Environmental Impact Assessment* (November 2002), Chapter 2, p. 3.

[6] Ministry of the Environment, Japan. *Report on Trade Liberalization and Environmental Impact Assessment* (November 2002), Chapter 2, p. 3-4.

3.1. UNCCD

The objective of the UNCCD is "to combat desertification and mitigate the effects of drought in countries experiencing serious drought and/or desertification, particularly in Africa, through effective action at all levels, supported by international cooperation and partnership arrangements, in the framework of an integrated approach which is consistent with *Agenda 21*, with a view to contributing to the achievement of sustainable development in affected areas" (Article 2). Rule making in virtual water trade can be regarded as "effective action" at the international level, as well as at the domestic level, by using both regulatory and voluntary mechanisms.

Although the UNCCD has no provisions on trade restrictions like the Convention on International Trade in Endangered Species of Wild Fauna and Flora, the member countries should "give due attention, within the relevant international and regional bodies, to the situation of affected developing country Parties with regard to international trade, marketing arrangements and debt with a view to establishing an enabling international economic environment conducive to the promotion of sustainable development" (Article 4). If the member countries change some environmental standards for water-intensive products, they can affect water utilization in trading countries. For instance, in an international river basin area, the upstream country may exploit freshwater resources by irrigation, at the expense of the downstream country and the affected downstream country may regulate importing of water-intensive agricultural products from upstream countries, then virtual water trade for peace would easily fail.

Another domestic policy is to provide subsidies as economic incentives or provide disincentives via taxation or water use surcharges. As is seen in carbon taxes in some OECD countries, the modality and level of the disincentives vary from country to country. This can affect the international price competitiveness of some industrial sectors of the respective countries, and some argue that it will also encourage multinational companies to relocate their production sites. Water pricing for agricultural and industrial sectors in both developed and developing countries should be reviewed with reference to possible consequences of transboundary movement of virtual water.

The virtual water concept can also be used, with or without governmental intervention, as a voluntary target for water resources conservation by the private sector. For instance, national or international agreements on voluntary target setting of water use for some industrial products among advanced member countries may provide trade-facilitation or trade-diversion effects inside and outside such a group.

Virtual water labelling for products, or information release for individual producers (for instance through the Global Reporting Initiative), is a consumer-oriented mechanism associated with social corporate responsibility and accountability. It will facilitate water education and consciousness for consumers, and it is a more sophisticated method than boycotting environmentally unfriendly products. This major shift in consumer consciousness can be seen in the increase in sustainable forestry management without a global forest convention, from which policy implications can be drawn for sustainable water resources management.

Another mechanism is one of procedural measures. It can be a legally binding environment impact assessment, or a non-legally-binding environment management system as set out by the International Organization for Standardization (ISO). Virtual water may be used in environmental assessment regulations or guidelines for trade export and official development assistance. A voluntary system can also work like a *de jure* standard, as is seen in the case of the integration of ISO14000 series into the WTO Agreement on Technical Barriers to Trade.

3.2. CBD and the Cartagena Protocol

The CBD aims at "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding" (Article 1).

The CBD defines biological diversity as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Article 2). Theoretically, some may argue that if embedded water is counted in agricultural products, the value of insect species for pollination may also be counted.

The CBD member countries recognized a variety of ecosystems, including agricultural diversity and dry and sub-humid lands biodiversity. Agricultural biodiversity includes the issue of water conservation. Despite a variety of foods for human beings, agricultural foods in today's global trading and consumption are limited to a few: rice, wheat, and maize. Rice and wheat are water-intensive products. In finding alternative food species, virtual water can be used as a measurement tool.

The Conference of Parties (COP) recognized the crossed links between biodiversity, desertification, and climate change, especially in dry and sub-humid lands. The COP also requested the Executive Secretary to prepare a proposal for the development of a mechanism to coordinate activities in these areas. For this proposal, virtual water trade can be used as a bridge among the three MEAs.

The Cartagena Protocol on Biosafety adopted in January 2000 seeks to protect biodiversity from the potential risks of living modified organisms. An example from modern biotechnology is the development of dryland-resistant crop seeds. Unlike the WTO SPS Agreement, the Cartagena Protocol takes a precautionary approach, and an advanced, informed agreement is established. In this procedure, before agreeing to the export of living modified organisms, exporters have to provide the importing countries with information necessary for decision-making. Like with the Rotterdam Convention on Prior Informed Consent, if the importing country does not agree, the water-saving living organisms cannot be traded.

3.3. UNFCCC and the Kyoto Protocol

The ultimate objective of the climate change regime is "to achieve […] stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Article 2). In so doing, the member countries should "develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods" (Article 4). Thus, there is a strong causal relationship between climate change and water cycles. In particular, the impact on water balances between drought/desertification areas and flood areas, from greenhouse gasses emitted into the atmosphere, should be identified.

Policies and experiences learned from the Kyoto Protocol can also be applied to the design of a successful system of virtual water trade. The main features of the Kyoto mechanism include: emissions trading, joint implementation (JI), and a clean development mechanism (CDM). Although these components of the Kyoto mechanism designed with different transferring units with different state and non-state participants are complex, units designed for virtual water trade may be linked to, or fungible with, the units for the Kyoto mechanism. It is not yet clear, however, whether the Kyoto mechanism should be revised and associated with virtual water trade.

In a sense, emissions trading can be regarded as a sort of "virtual air trade" among the developed countries (as listed in Annex B of the Kyoto Protocol). The Assigned Amount Units (AAUs) issued by the participating member countries can be transferred to, or acquired from, other participants as a supplement to domestic actions for their emission reduction commitments. If the causality between the anthropocentric contribution to climate change and water-related disasters is scientifically confirmed, AAUs may be used as a discounting factor for virtual water trade. Just as some criticize that emissions trading is trade in "pollution rights," virtual water trade should not be a trade in "exploitation rights".

JI projects can be undertaken in developed countries that have committed to greenhouse gas emission reduction targets. In so doing, they may transfer to, or acquire from, other participants Emission Reduction Units (ERUs) resulting from projects aimed at reducing anthropogenic emissions. JI would include renewable energy development projects, such as hydropower. In a similar manner, but in developing countries with public and/or private entities, CDM projects can be undertaken. In addition to reducing greenhouse gas emissions, they should also contribute to the sustainable development of the developing country that hosts the CDM project. Certified Emission Reductions (CERs) resulting from the CDM project in the water-stressed developing countries can be designed to be fungible with a virtual water trade unit.

Even if the virtual water trade unit cannot be linked to the units used for the Kyoto mechanism, a virtual water-trading rule can be designed independent of the Kyoto mechanism. Virtual water trading units can be used in unilateral, joint, or collective actions mainly undertaken by state actors, and cooperative actions undertaken with private sector participants.

4. Conclusions

What can be done in Kyoto? The virtual water session at the Third World Water Forum (WWF3) can appeal the relevance of a virtual water trade in global governance in two ways. The first is to issue and submit a written statement to the Ministerial Conference. The second is to persuade multiple stakeholders at the dialogue between the selected Forum participants and the Ministers.

As for a written statement, we can devise a list of policy proposals targeted to agricultural ministers, so that they can utilize them for the agricultural negotiations towards the WTO Cancun Ministerial. Because the deadline for submitting proposals for the modalities of the negotiations is the end of March 2003, WWF3 will be the last opportunity for the virtual water community as a whole to meet the world's agricultural ministers. The written proposal on virtual water trade should also be targeted for the main proposed ministerial meeting that will consist of water-related ministers with different portfolios, including energy, municipal supply of water, flood control, and the environment. In particular, on the environmental aspects, Kyoto is the perfect place to appeal the relationship between virtual water trade and climate change, because the convention centre was also the location of the Kyoto Protocol on Climate Change, agreed on in 1997.

As for the dialogue session with multiple stakeholders and the ministers, it is important for the virtual water community to collaborate with other major groups and forum session conveners to persuade the ministers. The nine major groups identified in *Agenda 21* are: women, youth, indigenous people, non-governmental organizations (NGOs), local authorities, workers and trade unions, business and industry, the scientific and technological community, and farmers. WWF3 will add two other stakeholders; those are legislators and journalists. Among others, farmers and legislators are main actors in mobilizing virtual water mechanisms in domestic politics. Other stakeholders and Forum session conveners are also important in implementing partnership projects on virtual water trade.

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8

Virtual water - virtual benefits?
Scarcity, distribution, security and conflict reconsidered

J. Warner

Abstract

Does water scarcity lead to war? A perusal of the literature of the early 1990s would certainly make us believe so. However, the last few years have seen a broadening in the debate, as an optimistic approach to globalised food trade enters the fray. The present article takes stock of this change and, to focus the debate, interrogates the virtual water thesis from a critical political economy perspective.

1. Introduction

Against the doom and gloom over water scarcity leading to water wars, a refreshing concept has taken central stage: virtual water, the water embedded in food that may go a long way to making up for water shortage in chronically parched areas, most notoriously the Middle East. Virtual water theory claims that the water embedded in traded cereals is a viable alternative to home-grown food. Ignoring this quantity paints an exaggerated picture of water scarcity. True, the Middle East may have run out of water in the 1970s, but today '[m]ore water 'flows' into the Middle than flows down the Nile into Egypt for agriculture' (Allan 2001).

Developed by Prof. J. Anthony Allan of the University of London, the concept has become increasingly accepted in water circles for a decade, but has of late taken centre stage in the fora of international water policy making. Its endorsement by a non-political figure, Willem Alexander, Crown Prince of Orange, in his 'No water, no future' document launched during the World Summit on Sustainable Development in Johannesburg, August 2002 (www.nowaternofuture.org) has lent it added respectability as an underestimated mitigator of water scarcity.

As an analytical concept, the virtual water thesis has been a tremendous breakthrough in the understanding of the global interrelations of water management, qualifying the current doom-laden perspective of water scarcity. It is not blind to its political effects either, vouching for its great 'political advantages' - predicated on the condition that the mechanism should remain invisible (Allan 2001: 33) to avoid social stress. This in itself is paradoxical - by publicising the concept and inducing a debate that now takes it to GWP level, it cannot remain invisible. The question, then, is whether the concept remains salutary when regarded as prescriptive.

The article starts by presenting the virtual water optimists as an alternative to the influential water wars perspective, and builds a (meta) theoretical case for it. Guarding against undue optimism, this article then takes a critical political-economy perspective, which is deliberately provocative to spark debate, arguing that the assessment of benefits underlying the virtual water thesis may be too rosy in light of its redistributive effects. Its optimism should be qualified in light of potentially counterproductive and potentially conflictive consequences for vulnerable actors within states' political economies, which calls into question who it is that reaps the (potential and real) political benefits and (water) security from virtual water. While virtual water can be the 'hidden factor' that facilitates adaptation, it may have its perverse consequences for socio-economic relations within and between nation-states, some of which are easy to skate over.

This analysis is clarified by a multi-dimensional understanding of resource scarcity. From a political economy view, scarcity and distribution are inextricably linked.

2. Two contending narratives: water wars and (virtual) water trade

Ensuring and allocating sufficient water of acceptable quality for a diversity of different uses and users compete for the same resource (Grigg 1997), in the face of dwindling supply, is a complex task indeed. Because of the complexity and uncertainty surrounding water management issues, they easily lead to value conflicts. This makes water (re)allocation issues 'wicked' (intractable) problems (van de Graaf & Hoppe 1992, Black 1995). A great many issues can easily be decided: they are straightforward and the evidence for and against is tidy, and people are clear on what they want. Water issues are not. Exactly because of the different social values people attach to it, not least in light of the resource's irreplaceability, water issues are at root essentially contested (Mollinga 1998). The great number of recent controversies over water projects attests to the intractable nature of those water issues, and they are likely to be intensified as the realisation sinks in that an adaptive shift to 'demand management' implies tough socio-economic choices (Ohlsson 1998). The shift from a supply-driven to demand-driven water economy is bound to create adjustment tensions.

The 1990s saw a sense of crisis in the water sector. The can-do mentality that long prevailed in the water world eroded after a succession of setbacks. There turned out to be a limit after all to limitless expansion of supply as rivers such as the Rio Grande stopped flowing into the sea and tapping additional water sources is going to be increasingly costly. Additional problems of salinisation and pollution plagued water-scarce areas. In response, fascinating technologies such as ‘Medusa bags’ and iceberg towing were tried to move water from water-abundant to water-scarce areas. Meanwhile new dams were increasingly controversial for social and environmental reasons, with severe public relations disasters over prestigious big dam projects, notably Narmada (India) and Arun (Nepal), triggering a watershed in donor thinking about dams. A switch to demand management and the need to include the voice of the general public in decision-making is now increasingly recognised.

Yet the question ‘what happens next’ produces a bifurcation between two schools, exactly because we don’t know what the future holds. When people are puzzled by uncertainty, complexity and turbulence (Rosenau 1990), they come up with simplifying stories to fill in the blanks (van Eeten 1997). These stories can take the form of theories and scenarios. Due to the uncertainty of water data, coexisting narratives can take root - pessimists may postulate a Malthusian 'water in crisis' narrative where optimists see a cornucopian 'fix' which promises an easy way out of the problems. This is especially relevant now that water has (finally) come to take centre stage. While 1980s saw the Water Decade, the 1990s really put water on the global resource management and development agenda in the period elapsing between UNCED Rio 1992 to WSSD Johannesburg 2002.

Let us first consider the pessimistic scenario. From the early 1990s, water came to be seen to be in crisis (Gleick 1993) - a concern with looming scarcity in closing river basins meant that the standard way of pleasing competing interests (increasing the pie) will not hold, so that competition for resources is increased. Academic, but mostly journalistic accounts sounded alarm bells over impending stress-induced 'green wars' and 'water wars' (Starr 1991; Bulloch & Darwish 1993; de Viliers 1999). The incendiary Middle East seemed a prime candidate for violent water conflict.

The underlying notion is that resource scarcity leads to conflict. This idea is unambiguously Hobbesian: each individual competes with other individuals for scarce resources. This creates a situation of mutual rivalry and threat characterized by chronic uncertainty and the perception of others as potential enemies. Indeed the strategic importance of resources is most clearly expressed in interventions to secure *access* to oil supplies, the Second Gulf War (1990-91) being a case in point (see e.g. Aarts, 1993) The role of strategic natural resources in international conflict has been known from time immemorial (Gleditsch, 1997), including the water weapon. The new element in the alarmist publications that started to appear was the connection between resource scarcity to regional *instability* – as a threat to *international security.*

It is useful to be clear what water use we are actually talking about. When we talk about water conflict, we rarely mean the few litres of water for drinking, washing and cooking humans need. Rather, some 80-90% in semi-arid countries is indeed taken up by irrigated agriculture. It is the central role of water in food production that made it central to a concern that food security, a basic human need, could be at risk[1]. After all, water deficits diminish agricultural production, and as a result, the rising food imports of populous nations like China were held to drive up world grain prices, to the detriment of low-income countries (Dimitrov 2002: 683). The reasoning thus basically revives the (Neo)-Malthusian thesis:

population growth => competition for resources => Tragedy of the Commons => acute resource conflict

As O Tuathail (1999) and others have argued, the alarmist Malthusianists of the 1990s have in practice legitimised an interventionist political agenda. To avert conflict and anarchy, they felt, states should be strengthened to bring order. Indeed, environmental security acquired foreign policy status as the U.S. set up

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[1]) There are many social, political and economic reasons why more water does not necessarily mean more food production. Beyond subsistence, water is not the only limiting factor to food production (Gorton 2001).

environmental hubs in axes of conflict (Dockser Marcus and Brauchli 1997). Post-September 11, 2001 the strengthening of the security state has only accelerated.

The 1990s' debate however closed on a growing consensus against the stark determinism (scarcity means war) pervading the literature. It was noted that intermediary variables mediated the not-quite-so-linear relationship between scarcity and violent conflict. In response to the doomsayers, a far more positive outlook of adaptive management and self-adjustment is holding sway. Aaron Wolf noted that water wars, though not unheard of, are very rare (Wolf 1995). Regime theorists, like Wolf, pointed at the growing numbers of international water treaties. Optimists like Röling (1994) argued that cooperation is a likely rather than a rare outcome of water disputes, once upstreamers and downstreamers will realise that unsustainable behaviour leads to joint misery, they will negotiate and work together in a process of social learning to improve water management and water sharing arrangements.

Homer-Dixon, one of the pessimists in the mid-1990s, started to change his mind, saying that Water wars were not so likely (ICRC 1998). He felt the 'water in crisis' narrative (Gleick 1993) ignored the strength of the social-political institutional set-up (Homer-Dixon 1995) and social ingenuity (Homer-Dixon 1995). Only if water scarcity is matched by 'social scarcity' (Ohlsson, 1998, see also below) there is reason to worry about 'water crises' with potentially violent, debilitating and destabilising consequences.

In addition to these social indicators, liberal internationalism gained a new lease on life in the virtual water thesis. Liberals have always contested the bleak view of unitary states, war of all against all on which Realism, the predominant school in International Relations theory, rests (Viotti and Kauppi 1999). They argue that interdependence and free trade leads to more interdependence, which in turn makes war obsolete. Interdependence, thus, eliminates rather than invites conflict.

Joining the debate from a hydrology perspective, Tony Allan has shown how a country like Egypt can get by in spite of its virtual lack of rainfall. He noted that the water pessimists tend to focus only on the fraction of precipitation that ends up in rivers, lakes and aquifers ('blue water'). This 'system' displays great losses from evaporation and percolation, and therefore losses should be prevented where possible. That fraction however is not lost to the hydrological cycle as a whole. Virtual water highlights the useful fact that soil moisture is productive in helping to produce new biomass. This root-zone water is abundant enough in temperate-zone countries to permit it being exported to water-poor countries.

The 'water wars' and 'virtual water' schools thus view (inter)dependence from totally different angles, not unlike the Realist and Liberal schools in International Relations (e.g. Viotti & Kauppi 1999). The 'water wars' scenario defines security as autarky and fears the dangers of international (inter)dependence, noting that downstream countries like Egypt and Israel are prone to upstream obstruction as they are net importers of water; conversely, the virtual water school sees a globally interdependent system full of possibility to balance unfortunate disparities.

The cheap food flowing from the water-rich to the water-poor countries has allowed water-poor countries to import encapsulated (virtual) water, thereby avoiding much of the drawdown of the scarce resource base caused by intense irrigation.

Virtual water therefore gives a more realistic indicator of the scale of national water deficits, and gives due heed to the increasing interconnectedness of the global trade system. It is a welcome antidote against the gloom of 'water wars' alarmists, usefully makes a case against autarky-seeking food strategies such as pursued by water-stressed countries. Virtual water makes food security still feasible despite a meagre local resource base.

Table 2.1. Two contending narratives.

Water in crisis	Virtual water
▪ 'Classical realism' ▪ Water is in conflict ▪ Malthusian ▪ State centred interventionism ▪ Scarcity => Water wars ▪ 'Blue water' counted only ▪ Resource dependence creates vulnerability ▪ Trade creates dependence ▪ Stress drives up food prices	▪ 'Liberal internationalism' ▪ Don't worry ▪ Cornucopian ▪ Free-market internationalism ▪ Water wars prevented by global food trade ▪ Root-zone water incl. ▪ Interdependence solves local shortages ▪ Trade resolves conflict ▪ Low food prices reduce stress

3. Some theory

Adaptive management, scarcity and allocation

In addition to its *prima facie* attraction as a problem-solving theory, there is also a metatheoretical reason why virtual water theory is on the ascent. Virtual water fits an emerging paradigm, which can be seen as the re-discovery of self-organisation. Complex systems can absorb shocks and adapt to imbalances - intervening in them will only delay the inevitable self-adjusting processes (Bak 1996).

The assumption here is that a complex system has self-equilibrating capacities when it is out of equilibrium. The question is, however, whether virtual water should be seen as a tool rather than a theory, as prescriptive rather than descriptive. The writings on virtual water suggest that it is a serious policy prescription for water-poor countries: integrate with the world economy and avoid senseless fighting over water. The trick, then, is to manage the resource such that the self-equilibrating forces in a stressed system are facilitated rather than counteracted.

As said above, environmental *stress* is considered the driver for conflict and instability. Now stress is the difference between a challenge and the coping capacity (Lazarus 1966). In these terms, virtual water enhances the coping capacity, de-stressing the claim on the environment by virtually enhancing the water supply.

In 'management' terms the implication is that the perceived stress can be actively relieved from two sides - improving capabilities or reducing needs. Kooiman however doesn't mean to support top-down interventionism - rather, tweaking the preconditions rather than the parameters themselves can help spontaneous forces gain equilibrium. In Kooiman's writings on Governance, inspired by the chaos theory popularised by Prigogine and Stengers (1991), the out-of-equilibrium approach is not seen as a problem, but as an opportunity for progressing to a new equilibrium at a higher level.

The virtual water thesis, then, sees the world as one system, relying on the structural, self-adjusting forces in the global political economy, redistributing scarcity and thus preventing violent conflict over water.

But what kind of water scarcity are we really talking about?

Scarcity can be differentiated into a number of types. Absolute scarcity tells us how much water is there on earth, in solid, liquid or gaseous form. Yet it is increasingly realised that there is no question of absolute scarcity. Apart from technical hurdles, there is still plenty – though maldistributed - freshwater to go round. The idea of an inescapable water and food crisis is a veritable Malthusian fallacy.(2)

Technological scarcity denotes how much we an actually retrieve with the limitations of current technology. There may be plenty of water in an aquifer hidden under 1 km of rock, but it is pretty hard to get it out of there,

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(2) In the late 18th century, Thomas Malthus predicted that food production could never catch up with population increase, but underestimated technological progress.

especially if economic considerations are taken into account. These indicators are interesting, but tell us little about how much water can be used in practice. On an absolute scale, there is enough water to go round - the problem is accessibility and the very skewed distribution across the world.

The key limit to water availability and scarcity is redistribution. According to classical economists, the Invisible Hand of the market takes care of optimal distribution through trade. Of course, the optimal utility curve does not necessarily mean an optimum on everyone's utility curve. Even without intervention, trade has its winners and losers.

But even if that weren't the case, the unadulterated free market is a fiction. Regulation and allocation interfere with free-market allocation. It is such choices that actively impact on the distribution of freshwater resource that are key to the sense of scarcity. Human choice has a strong bearing on actual local availability of water, not to mention the perception whether this amount is sufficient. The wisdom of such choices depend on yet another type of resource scarcity - a type studied under the slightly confusing moniker 'social scarcity' (Ohlsson 1998), which denotes the scarcity of adaptive social, political and institutional resources. Social ingenuity and institutional maturity, it is felt, can counteract resource scarcity to facilitate a change to water-extensive production and more sensible and just distribution pattern. The Human Development Index is used as a proxy for ranking states in terms of this concept. The more robust and resilient this set-up (and operation) is, the more likely a process of socio-economic redirection away from water-intensive practice is likely to be, leading to constructive adaptation rather than destructive conflict. In a water management context, it refers to a society's ability to make a very necessary change to a more water-extensive economy under the stress of impending water shortage (Ohlsson 1998).

Even where there is an appropriate institutional framework, however, water may be used unwisely from the perspective of sustainable water use. 'Economic scarcity' (in fact political-economic scarcity) is the result of choices made about how water is distributed. For political reasons - legitimacy being prime among them - a country may pursue a wasteful rather than sensible economic strategy. The agricultural ideology exemplified by the 'hydraulic mission' (Reisner 1995) is the well-known exponent of that. Political choices can go against water-saving developments. At the turn of the 1990s, Israel, a technologically advanced and institutionally developed state, saw a marked decline in its water use, seemingly leading the way in what Hajer (1995) has called 'ecological modernisation'. However, the pattern was reversed again under the Likud government and as Israeli-Palestinian relations soured.

Awareness of this puts a damper on the optimism of modernisation theorists. Classical economy fails to asks why goods are locally 'scarce' in the first place. While classical economists have tended to take the existence of a discrete level of 'scarcity' for granted, political scientists have long pointed out that the level of 'scarcity' is not given, but results from power struggles and political processes. Monopolistic tendencies can make an otherwise abundant resource seem scarce, as access is restricted to the many.

Warner (1992) has called attention to what he calls *'induced' resource scarcity*. Water, and food, can be made scarce - they can be captured (Homer-Dixon 1994) or barriers to access can be made insurmountable, as the resulting exclusionary distribution pattern disenfranchises a majority from accessing enough water to fill their needs.

Table 3.1. Scarcity typology.

Type of scarcity	Limitations	Author
Absolute	Physical existence	
Technical	Technological (and economic) limits to exploitation	
Economic	Macroeconomic policy choices	Sexton 1992 e.a.
Social	Social ingenuity; institutional/political maturity	Ohlsson 1998
Induced	Political strategy; Resource capture	Warner 1992; Homer-Dixon 1993

The scarcity of water in specific localities and the abundance on the world market of cheap food is thus a political as well as an economic choice, impinging on scarcity and distribution patterns.

4. Some problems with a virtual water strategy

While it opens exciting vistas and dampens unnecessary panic attacks, the virtual water thesis doesn't come without its problems. This section inventories some problems with virtual water theory form a security and vulnerability perspective.

Security is the state of being without a care (from the Latin *s[in]e*) *cura*. The German word *Sicherheit* nicely collapses three of its connotations – security, safety and certainty – into a single concept. Section 4.1 points at situations in which 'being without a care' equates carelessness, and argues that virtual water can promote that state.

Section 4.2 asks whose security is being served, making some observations about the role of virtual water in international security arrangements. Following on from that, Section 4.3 argues that virtual water as a strategy can exacerbate vulnerability for negatively affected groups. It is in part inspired by the structuralist 'vulnerability' approach in Disaster Studies (Hewitt 1983 and others) which claims that economical and political power differentials lead to unequal distribution of vulnerability within global and domestic systems, in turn bringing about the social, political and economic exclusion of the poor and powerless.

4.1. Undersecuritisation – living in denial

The virtual water school claims that virtual water stops water wars breaking out. It is never possible to prove the counterfactual that conflict would happen had certain measures not been taken (Gleditsch 1998) It makes *a priori* sense that less scarcity means less conflict, but it is a tricky hypothesis to maintain, especially since there has not really been a water war so far (Wolf 1995 and later publications). This becomes clearer if we take note of the important insight that conflict over water is very often the focus of wider conflict (Warner 2000a and elsewhere). Countries where water is relatively abundant have argued over water (Turkey, Syria and Iraq) in part because Turkey has intensively dammed up the Euphrates and Tigris strengthening its upstream position in such a way that downstream states feel uncomfortable with its neighbour's strategy. Moreover, a whole complex of historic factors are at play which conflict over water brings to a head (Warner 1999).

While preventing violent conflict surely is something to strive for, it is more doubtful to look for approaches that avoid any kind of (political) conflict. Allan (e.g. 2001) has repeatedly noted that virtual water is so successful because it is invisible, playing beyond the general political debate. Yet its very 'invisibility' may enable what Buzan *et al* (1998) have called 'undersecuritisation', the exclusion from the policy discourse of a security problem of crisis proportions warranting immediate action. As national policymakers become or remain aware of the 'secret reserve', they may be tempted not to do anything long-term oriented while virtual water bails them out in the short run. This long-term perspective may require investments in technology, social ingenuity and democracy to facilitate a transition to a demand-management strategy rather than a tacit dependence on trade flows.

This lends a poignant flavour to Tony Allan's uplifting dictum, 'the pessimists are wrong but important, the optimists are right but dangerous' - as their optimism may incite policymakers not to do anything.

A blind eye to an overstressed resource base also bails autocratic state out of a necessary engagement with civil society. As Luciani and Beblawi (1989) have argued, oil wealth and foreign aid have long bailed politically insecure 'rentier states' out of a democratisation process less endowed countries have been forced to initiate. A strategy that avoids a crisis over natural resources also avoids the kind of reflective process that can spur ecological modernisation and democratisation (Ohlsson 1998).

Democracy is institutionalised conflict; preventing this conflict to play out over water could prevent a necessary change of policy. Deliberate non-politicisation sustains non-participation in water management, while for a transition from supply to demand management, it is the very support and participation of 'civil society' that will be required to prevent adaptive social stress, not as a legitimising add-on but rather as an integrated element of the decision-making and implementation process.

Participation however presents special challenges, notably the loss of control which countries pursuing virtual water strategies may find threatening. Participation easily becomes polarised over competing alternatives and contested values, and thus *political*. Pessimists such as Mollinga (1998) even claim that water is *always* political, in the sense of 'prone to contest over the allocation of scarce resources (Haywood).. It is bound to elicit or be the focus of social conflict - which may not necessarily revolve the water resource itself. Seen in that light, a strategy that avoids the process of contestation by avoiding participation (and thus *depoliticising*) therefore delays inevitable systemic clashes that may be far more damaging when ignored than when politicised an accommodated.

4.2. Whose security?

This is especially pertinent to the region where virtual water is most relevant, the Middle East and North Africa. Like in many developing countries, MENA states are often less than well established in terms of legal-administrative control and legitimacy.

As Ferguson (1996) cogently argues, states in search of autonomy and administrative control are easily tempted to use development projects for politico-strategic as well as developmental reasons.

States often initiate intervention projects such as dams and irrigation projects to reduce dependence on upstream states and improve the food production base. But projects distribute water *security* among stakeholders (Warner 2000a) and may be used as a strategic instrument for allocating (inclusion or exclusion) land and water to (dis)favoured groups (Warner 1992). Thus, irrigation projects also sideline rain-fed agriculture, displace local people and upset established systems of land tenure.

The rationale of serving the national interest thus acts as an depoliticising agent, but can be said to be thoroughly political.

Returning to virtual water, the centralised importation of cheap grain is like creating a food 'reservoir'giving the state a monopoly on the food market, allowing it to create a client base in the major cities, distributing food in exchange for political allegiance. Thus, the security of the recipient states was enhanced, as well as the allegiance of those states to American foreign policy goals. This allegiance brings a degree of political dependency some would denounce as neo-colonial.

The above points at the difference between security for states and states for individual sectors. The same difference obtains between international security and security for specific states. Just like water conflict is not necessarily about water, food (virtual water) trade is not necessarily about trade, but about serving foreign and domestic policy goals. At first glance, it seems that intensive food trade is clearly seen as a benefit by both im- and exporters. Food surpluses in the US and the European Union found a willing outlet, in the form of heavily subsidised supplies or aid which developed under the post-war Fordist system of production (Warner 2000b). Under U.S. Public Law 480 agricultural surpluses were also donated to Egypt and India, not because these countries were starving but to enable skipping the agricultural stage of development to enable industrialisation. It is telling that only in the late 1990s food aid to Egypt, a middle-income country and strategic 'policeman' in the troubled Middle East, was discontinued.

4.3. Vulnerability

Another problem with a virtual water strategy is that avoiding political stress by tapping the adaptive capacity of the world trade system may displace the stress. 'Adaptation' suggests a peaceful process without political conflict, struggle or bloodshed. But adaptive processes can be Darwinian, messy and rough around the edges.
Virtual water as a prescription promotes banks on increasing globalisation and interdependency. Integration in the global food trade brings with it increased exposure and sensitivity to price shocks that comes with the ebbs and flows of world trade Moreover, the current low prices are by no means the result of an free, untrammelled global food market. Over the last few decades, the world price in food grains has been falling steadily as a result of bringing down tariff walls, as well as dumping agricultural exports by the biggest producers, the U.S. and Europe. Agriculture in the EU and the US is heavily subsidised at several stages of the production process - land, inputs, transport, marketing, export. Someone is paying these subsidies, and may not want to carry on paying them forever. While agricultural lobby progressively lose their traditional strength, agricultural subsidies in the North are bound to decline over time, raising world prices.

Cheap virtual water, then, banks on unsustainable trade distortions. Once taxpayers in the West stop shouldering agricultural exports, and/or the World Trade Organisation outlaws it, food prices will rise. Who is going to pay that bill in poor but trade-dependent countries?

It is also important to note that the expedient of virtual water is not open to all water-scarce countries, only those who can afford it or have powerful friends. For strategic-political reasons Egypt gets more food and financial aid than populous upstream Nile riparian Ethiopia, which is currently reliving its 10-year cycle of famine, not to mention military aid to stop Ethiopia from developing its own water resources. Those who get food aid pay in another way, with political currency, and are in turn vulnerable to the possibility of losing the comforts of international aid in due course.

While the Crown Prince commends the potential of virtual water to counteract local water scarcities and recommends that countries 'relax national self-sufficiency targets' he sensibly adds that this should take place under a 'fair and reliable system of international trade' (www.nowaternofuture.org, 2002: 8). This is a crucial addition - many would say that today's international trade system is far from 'fair'.

Global trade however is hardly a level playing field. For poor countries trade means participation in a system dominated by powerful interests that are hard to control. Political economists show that food scarcity can be induced as well by food multinationals who can keep giant stocks to manipulate prices (Ritchie 1992).

Interdependence thus means opportunity for some, but dependence and vulnerability for others. Virtual water trade delivers water-poor states from one type of dependency, that on its limited resources, but can usher in dependency of another type: dependency on the unequal terms of world trade. One only needs to consider the dependence of OECD countries on OPEC's oil to imagine what that dependency is like - as indeed some commentators in the US advocating the deployment of the 'grain weapon' to counter the energy producers' oil weapon in 1973 (Allan 2001: 166).

It was noted above that state security is not the same thing as sectoral security. Virtual water trade may be a happy outcome at the state level, but it closes its eyes to more worrying redistributive effects within the state. If we look beyond the interests of state elites, we get a different picture. By undercutting the domestic agricultural base, which cannot produce as cheaply as the world market producers, cheap food imports crowd out the domestic market and erodes the potentially powerful farming lobby.

The substitution drive may even intensify the water intensity of production. If Egyptian grain farmers are outcompeted by global grain, these crowded-out cereal farmers may switch to more remunerating but water-intensive export crops such as cotton, making the savings in water use negative.

Others will move out of agriculture altogether, swelling - with few exceptions - the numbers of the poor and destitute in the mega cities and, ultimately, add to existing migratory patterns East-to-West and South-to-North. Urbanisation means dependence on food handouts and remittances for the local poor, who come out of the equation having less access to clean, safe water and are marginalized even further by the loss of the security of livelihoods and rural social fabrics.

Urbanisation, food aid and globalisation of trade and (American) culture - McDonaldisation - are also bound to spell change in global dietary habits. In the wake of urbanisation and globalisation dietary preferences change, as people start eating more water-intensive foods - notably meat, which can be said to be virtual cereal (processing water into cereal into beef). It is interesting that Turton's analysis of Botswana, which commendably comprises imports as well as exports, looks at maize, wheat and sugar but not meat, of which it is a major global exporter (Turton 2000). As tariff walls and subsidies for domestic production in the West come down, agricultural imports from the South may well expand, boosting virtual water exports on the part of those pursuing a breadbasket strategy. While in itself a boost to Southern economies, countries pursuing the strategy may refuse to take their water reserves into account – Saudi Arabia’s grain and vegetable exports from the desert an example of how a desire to be a player defeats common sense.

Food aid is a particularly culpable factor. It changed consumption patterns to products that may not be suited to local production preconditions.

Especially beef has a spectacularly inefficient transformation rate in water to cereal to beef. If so, isn’t it a form of food substitution and water intensification rather than conservation?

Viewed in this light, it is not only the taxpayers in the West but also the poor of the South who are paying for agricultural trade. Food dependency does not necessarily hurt the power elite in the globalising economy, but the picture looks different in the hinterlands.

5. Expanding virtual water analysis

The above has highlighted aspects that have remained underanalysed in publications in virtual water. In this section, some additional points will be made and the argument summarised.

Virtual water analysis tends to concentrate on imports to water-starved countries. We feel it should pay far more heed to the consequences of virtual water exports, not only in the form of cereal or rice but also of cotton, meat (virtual cereal!) and clothes.

Also, taking the concept to its logical conclusion, virtual water analysis should work at lower levels as well. Prof. Allan has a point where he lambasts environmentalists for being too enamoured with integrated catchment management as the sole focus of action (Allan 2001, see also Wester and Warner 2001 for a more elaborate critique), but if embedded in a multi-level analysis it certainly has enormous merit over managing shared water units according to administrative rather than geographical boundaries.

Calculating what goes in and out at the regional level and the catchment level can show shortages and surpluses that can be managed to achieve better balance of water distribution. This is already happening in material form through Inter- (and Intra-)Basin Transfers, but as a rule overlooks the encapsulated transfers.

On the other hand: where do you stop? Virtual water analysis ignores other factors, inputs that make up food production, such as land, nutrients and energy, not to mention human labour **-** out of those, especially energy seems a candidate for serious inclusion in the statistics, as the resource intensity involved in global food transport is tremendous and subsidies considerable.

A brief research agenda pointing the way forward would read as follows:

- The research agenda on virtual water should comprise virtual exports as well as imports, and look at meat as a form of (highly inefficient) encapsulated water - and energy.
- To assess the proper 'water balance', and see if there is still a positive outcome, if social costs and benefits are included in the analysis.
- The analysis should look at the redistributive effects of a virtual water strategy within and between countries – in terms of water distribution and security distribution
- It should consider the political and environmental effects (stress) of undersecuritising water.

6. In closing

The virtual water hypothesis makes *a priori* sense and could, if used wisely, help forestall conflict. The Green Cross' 'Water for peace' project certainly takes this view. The virtual water thesis posits a self-restoring mechanism in a world out of equilibrium due to the sharply unequal global water distribution picture. However, there is a problem with the underlying assumption that this equilibrium will be reached spontaneously, and that it will benefit everyone. It will redistribute stress and insecurity in ways that may heighten rather than dampen social conflict. While a reserve army of virtual water sources can alleviate the stresses of adjustment, it also takes the human factor out of the equation.

Policymakers should realise that virtual water has redistributive effects on actors' water and food security positions between and within states. Intensifying these effects by relying more on trade puts some countries and sectors at a distinct disadvantage, and as a consequence increase tensions and conflict potentials.

Ironically, the ‘invisible hand’ of virtual water will not long remain invisible. Even where it is not a conscious effort, the until recently 'invisible' mechanism is rapidly being exposed to the world and, thanks to its princely endorsement, is heard loud and clear by policymakers all over the world.

If virtual water reduces the stress on the resource base, should countries actively manage trade flows such that they most efficiently redistribute root-zone water.

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9

Virtual water eliminates water wars? A case study from the Middle East

J.A. Allan

Abstract

The Middle East is very poorly endowed with freshwater: the region ran out of water resources to meet its strategic needs—for domestic and industrial use as well as for food production—in 1970. Despite depleted water resources and growing water demand pushed by population growth, international relations over water have, if anything, become less tense since 1970. The reason is that water has been available on the international market in the form of “virtual water.” Indeed, economies that can import grain avoid having to mobilize scarce freshwater from their own resource base to produce wheat themselves. By the year 2000, the Middle East and North Africa were importing fifty million tons of grain annually, satisfying the largest demand for water in the region—food production. The remaining 10 percent of water demand for drinking, domestic, and industrial use may soon be met through low-cost desalinated seawater. The global political economy of water use and trade has had important impacts on the way water is perceived in the Middle East. But at the same time, the impact of the global system has been perverse in that the availability of virtual water has slowed the pace of reforms intended to improve water efficiency.

Introduction

The Middle East is the most water-challenged region in the world, with little freshwater and negligible soil water.[1] Water is therefore a key strategic natural resource, and realist theory, as well as popular intuition, has it that the scarcity of water in the region will lead to water wars. Despite growing water demand, the Middle East has shown no signs of a water war since some minor military events in the northern Jordan Valley in the early 1960s.[2] On the contrary, there is much evidence of cooperation over scarce water resources in the region, especially in the Jordan River Basin, where freshwater is scarcest.[3] Water is too important to be left to the uncertainties of *rapports de force*.[4]

Many Middle Eastern economies must use fresh surface and groundwater resources for food production. In contrast, in temperate regions, up to 90 percent of the water used in food production comes from naturally occurring water in soil profiles, called soil water. Soil water differs from freshwater in that it can only be used in agriculture to produce crops. Freshwater can be used by all sectors (for domestic, industrial, and agricultural activities) and can be lifted, pumped, and transported. It can therefore be assigned an explicit value in commercial transactions. Although soil water can only physically be used *in situ*, it can also be “moved” and exported through agricultural production and trade.

Indeed, at the global level, soil water resources are in surplus. Fortunately for the water-short economies of the Middle East, this soil water can be made accessible via trade in staple food commodities such as grain. Every year, farmers and traders in the Middle East move volumes of water equivalent to the flow of the Nile into Egypt, or about 25 percent of the region’s total available freshwater. The water “imported” in this way can be called “virtual water.”[5] To produce one ton of wheat requires one thousand tons (cubic meters) of water. Importing a ton of wheat therefore relieves a community from having to harness one thousand tons of its own water resources.

The purpose of this analysis is to show, first, that the perceptions of water resources in the Middle East are constructed, namely that the notion of water scarcity is based on too narrow an interpretation of freshwater availability. Second, the reason this constructed perspective has endured thus far lies in the effectiveness of the international political economy, which has in fact solved the region’s water resource problems, albeit invisibly and silently. Finally, it is important to draw attention to the impact of the international political economy on the region, which has been perverse as well as favourable. Indeed, the global trade system has slowed the pace of water policy reform and has distorted international relations where shared freshwater resources are in contention.

Constructed knowledge and the "sanctioned discourse" on water in the Middle East

In the realm of international relations theory, the case of international shared waters in the Middle East can be understood within a non-rigorous, realist framework. In each river basin there is a hegemon, such as Turkey in the Euphrates-Tigris river system, Egypt in the Nile river system, or Israel in the Jordan Basin. Within a realist framework, riparian relations can be explained in terms of each country's capacity to project power.[6] Functional approaches and regime theory have not provided a useful basis for analysis because there are no international structures that work in the region.[7]

Contentious issues arising over shared freshwater resources are also embedded in what Barry Buzan calls "security subcomplexes." Securitisation theory, well articulated in the case of the Middle East by Buzan, contrasts the high politics of extreme circumstances—"security politics"—with the "normal politics" that they interrupt, but finally confirms the realist analysis.[8] Buzan identifies the Middle East and North Africa as a significant security complex containing three subsystems. Whereas in the Gulf and in North Africa water is only a peripheral issue, the competition over water resources is central to the eastern Mediterranean subcomplex, comprising Israel, Jordan, and Palestine. Yet, despite the importance of water as a source of tension, its significance is limited in negotiations between the Jordan Basin riparian states. Instead, symbolic issues have traditionally dominated negotiation agendas.

Water is just one of many contentious issues with which neighbouring political economies in the Middle East must contend. For example, the major issues between Jordan and Israel before their negotiated Peace Agreement in 1994 were peace, territorial boundaries, and water.[9] In the case of Israel and Palestine, there have been five issues—Jerusalem, territorial boundaries, settlements, refugees, and water.[10] When numerous issues are at stake, linkages in negotiation are unavoidable. However, the symbolic significance of some of the issues at hand, such as defining the status of Jerusalem, determining borders, and gaining a lasting peace will typically overwhelm other, economically significant disputes (e.g., joint water management, the right of return for refugees)—even when these are strategically profound. For example, in the 1994 Jordan-Israel Peace Agreement, gains in terms of symbolically charged issues such as suing for peace and obtaining favourable territorial boundaries came at the expense of losses on water claims for Jordan.

In fact, in the Jordan Basin, water policy, including water allocation decisions and joint management of common freshwater resources, is typically formulated based on "constructed knowledge," or the product of biased views toward water resource security. Indeed, important decisions regarding water resources depend on public perceptions of water security, which are manipulated and distorted—i.e., "constructed." Policymakers purposefully downplay their economies' water deficits because politically, such a risk-free approach to water policy is easier than to confront the seemingly intractable problems posed by acute water scarcity. What has sustained these distorted, "constructed" notions of water security thus far are the global trading system and access to virtual water.[11] Throughout the past fifty years, Middle Eastern governments have leveraged the global political economy in order to implement otherwise unsustainable water allocation policies. Yet, instead of publicizing the contribution of international trade to solving the region's growing water scarcity problem, policymakers have kept "virtual water" imports, in the form of grain and food commodities, invisible economically and silent politically. Indeed, to discuss them publicly would contradict deeply held beliefs regarding water security (as well as each country's independent national water policies), which would be politically destabilizing to say the least.

As a result, the spectacularly successful benefits of international trade, conforming to classical notions of comparative advantage, have been subordinated to the "sanctioned discourse" on water in the region.[12] The "sanctioned discourse" on water is that Middle Eastern economies only need a little more water to be "secure." Politicians, the agricultural sector—the single largest water consumer in local economies—and the media all reinforce the sanctioned discourse and advocate self-sufficiency in water and food production, without ever clearly defining these terms. These policy goals, highly charged politically, are rarely examined or challenged publicly. For politicians and policymakers, the importance of virtual water is that it allows the pretence, perhaps better described as the fantasy, of claiming that water deficit problems are being solved domestically and that their countries are achieving self-sufficiency in water and food production.

However, such distorted risk awareness regarding water usage among the region's populations has significant, adverse impacts on the way negotiations over water resources are approached or even initiated. The sanctioned discourse is equally evident in the efforts riparian states make to avoid negotiations over common water resources and in their negotiating strategies once they have initiated conflict resolution efforts. In the case of the Israel-Palestine negotiations, a significant turning point was reached when the focus of the negotiations shifted from the contradictory principles of sovereignty, espoused by the Palestinian negotiators, and prior use, argued by Israel, to those of equitable utilization. Equitable utilization will always be difficult to implement, but it does have the merit of integrating international and national economic processes into a final agreement, thereby enabling a solution that improves the livelihoods of local populations instead of merely focusing on the narrow issue of water deficits. Access to virtual water and, in due course, desalinated water will contribute both to economic well-being and to decreasing water scarcity by freeing up scarce freshwater resources for other, non-agricultural purposes.

That such constructed knowledge dominates water policy is not unusual, nor even reprehensible. Recognizing the phenomenon of constructed knowledge is, however, critical for understanding the discourse that surrounds water security and water policy in the Middle East.

The Jordan Basin

The relations between riparian states of the Jordan Basin have been characterized by very intense international politics over diverse, yet linked issues. Contention over water has proved to be subordinate to symbolic and territorial issues such as peace, Jerusalem, borders, settlements, and the return of refugees. The riparian states in the basin have all been strong adherents of the “sanctioned discourse” on water. Even Israel has relapsed into a confusing and contradictory water policy since the peace talks began in 1992, despite having charted a new course in the mid-1980s that rejected the usual assumptions about water politics. Jordan is currently in a transitional mode and the government’s water policy seems to be moving away from the sanctioned discourse. Water policy in the Jordan Basin as a whole has been a parable of how political impediments attenuate principled innovation.

The history of hydropolitics in the Middle East during the second half of the twentieth century has been characterized by intense, occasionally armed, hostility. In the late 1940s, the economies of the region could be regarded as water secure, with enough water to meet both domestic and industrial needs as well as food production requirements. Since then, however, the population of the basin has increased from about three million to over fifteen million today. Accordingly, the use of freshwater increased about six-fold in half a century. While the region’s water endowment has remained the same, heavy technical interventions have taken place to divert water for various purposes, radically altering the levels and patterns of use. Initiatives like Israel’s urban wastewater reuse program have not contributed significantly to increasing water resources. Clearly, the water resources of the Jordan Basin countries have been very seriously tested, and in these intense demographic and economic circumstances, it is remarkable that there has been so little conflict over water.

The Jordan Basin is also a useful laboratory in which to observe the miraculous workings of economically invisible and politically silent “virtual water,” accessible primarily through the international grain market.[13] Given the current population of the basin, the region would need about fifteen billion cubic meters of water to be self-sufficient. However, there are less than three billion cubic meters of freshwater available annually, not counting additional soil water in the northern part of the basin, which is estimated at one to two billion cubic meters, but which is not fungible. Yet this annual deficit of ten to twelve billion cubic meters, which has existed since the 1950s, is not publicly discussed. Nor is the fact that neither Israel, Palestine, nor Jordan can meet their food needs relying solely on their freshwater resources. Instead, policymakers speak of running out of water in the future. The constructed discourse about the tractability of the water supply problem overwhelms any attempt to introduce the politically unwelcome statistics of stark deficits.

Finally, there has not been a significant amount of negotiation over water issues either. The only agreements reached came toward the end of the period. In 1994, Jordan and Israel signed a peace agreement with articles specifically addressing water.[14] In this sense too, the Jordan Basin provides a useful case study because negotiations over water, albeit strongly linked to other highly politicised issues, have already been initiated, though only long after water shortages became acute.[15]

Political ecology in the Jordan Basin

The political ecology of water resources and management in the Jordan basin countries in the last half of the twentieth century can be considered by decade. The 1940s were a period of massive social and political disruption. The armistice, which marked the end of the Arab-Israeli conflict of 1947-48 and the establishment of a Jewish state, left Israel and Jordan with borders different from those during the period of British administration and different from the boundaries recommended by the UN Partition plan.[16] The new territorial boundaries guaranteed that access to water resources would be contentious.

From 1952 to 1955, the United States tried to devise a rational division of water resources among the Jordan Basin riparian states. The U.S. government sent a special diplomatic mission—the Johnston Mission—to negotiate a basin-wide arrangement for optimising water allocation between Jordan, Israel, and Syria.[17] The U.S. mission's approach to water resource management was imbued by two ideas. First, U.S. water experts were convinced that science and engineering, backed by substantial government funding, guaranteed the success of such ambitious projects. Second, the Johnston Mission was determined to avoid the detrimental consequences of environmental mismanagement. Their model was the Tennessee Valley Authority (TVA), which was set up to address environmental, economic, and social challenges in a poor region of the United States during the 1930s. The lessons from the TVA showed that to reverse resource depletion, both careful planning and strict regulation of resource use were necessary, whereas state-of-the art engineering could minimize the environmental damage of large-scale water development projects.

The Johnston mission was successful in the technical aspects of resource evaluation. It even came up with numbers that satisfied the water professionals of the three riparian states. But by 1955, it was clear that an agreement for sharing freshwater resources contradicted the polarized politics of Arabs versus Israelis. The ministers of the Arab countries rejected the Johnston Plan. Despite this political failure, the water allocation proposal outlined in the plan still provided a reasonable basis for eventually negotiating a basin-wide agreement. Johnston recommended that Syria receive thirty-five million cubic meters per year from the upper Yarmuk tributaries.

Nevertheless, following the Johnston Mission, each riparian state adopted unilateral water policies, which only exacerbated already tense interstate relations. There was even some evidence that armed conflict could occur over water. Israeli policy was geared toward moving what it regarded as its share of Jordan water from the Jordan Valley to the coastal plain. As a result, the 1950s saw the most rapid development of groundwater resources in the history of the area as Israel increased water abstraction from coastal aquifers. Israel managed to mobilize over one billion cubic meters per year of additional water for irrigation. Syria had also extensively developed its irrigation infrastructure, diverting, since the 1960s, roughly two hundred million cubic meters of water annually from the Yarmuk River. Jordan, meanwhile, had expected to use up to 80 percent of the water siphoned off by its two neighbours. One project Jordan had been particularly keen about was the construction of a dam on the lower Yarkmuk to control the flow to Jordan's benefit. Proposals to build this dam surfaced periodically, but the annual water flow of the Yarmuk eventually became too unreliable for a dam structure to be economically or environmentally viable.

As a result, serious contention over the waters of the upper Jordan Basin arose throughout the 1960s. Water-related armed conflict took place as both Syria and Israel were successful in frustrating their neighbor's intent to divert water. Syria abandoned its plan to divert water from the Banias to the Yarmuk. Israel was forced to opt for the very expensive policy of building a water carrier from the lower-level Lake Tiberias-Kinneret rather than diverting water from the higher levels of the upper Jordan Basin. In June 1967, war broke out, eventually leaving Israel victorious and in control of the entire upper Jordan Basin as well as the West Bank aquifers. Water was neither the trigger for the war nor the main goal of any of its adversaries. The outcome of the war did, however, determine regional hydropolitics for the next two decades. In the absence of formal agreements, Israel and Jordan had continuous informal meetings and arrangements that enabled them to allocate water during the twenty-five years following the 1967 War. Both countries have tended to take the numbers produced by Johnston in the 1950s as a basis for their discussions.

Between 1986 and 1993, the politics of water allocation in Israel swung dramatically from a precautionary to an opportunistic approach. An environmentalist campaign to reduce water to irrigation gained purchase during the drought of 1986. At the same time, the United States put pressure on Israel to improve its economic efficiency, including the agricultural sector, by threatening to withhold a $10 billion financial arrangement. The 1991 drought reinforced the policy of economic and environmental consideration. However, two events brought a swift reversal of policy. First, there were unusually heavy rains in 1992, which restored the West Bank groundwater levels and Lake Tiberias-Kinneret to pre-1967 levels in the space of a few weeks. Second, the peace talks started. The coalition of environmentalists, water professionals, and politicians, which had succeeded in introducing and sustaining the cautious water management policy since 1986, lost influence. A coalition focused on security and agricultural interests gained the upper hand. Levels of water withdrawal, which had fallen from two billion cubic meters per year in 1985 to 1.6 billion cubic meters in 1992, rose within three years to 1985 levels.

Israel had demonstrated that it could run its economy effectively with 1.6 billion cubic meters of water per year—less than the peak usage of two billion cubic meters per year, a significant volume of water in a water-scare region. Palestinians in Gaza and the West Bank only use about two hundred million cubic meters per year. All of Israel's non-agricultural livelihoods, those in industry and services, which produce over 97 percent of the GDP, use only about one hundred million cubic meters per year. Why did Israel reverse its policy? Why did the security concerns take precedence over environmental risks after 1992? The heavy rains certainly facilitated the policy change, but the new risk presented by the newly launched comprehensive peace negotiations led some elements of the Israeli political elite to argue for an increase in water use to improve their bargaining position at the negotiation table.[18] Indeed, since Israel is a downstream state with regard to the Western and Northeastern aquifers (called the "Mountain Aquifer" in Israel), Israeli negotiators would have more leverage over their counterparts if Israeli water policy advocated a high level of water abstraction. Since any water-sharing agreement would likely allocate water resources based on the amount consumed rather than absolute estimates of water availability, Israel stood to gain a larger share if it consumed more prior to the settlement.

In 1994, Jordan and Israel reached an agreement over water, and Palestine and Israel launched the Oslo peace process.[19] Water need not be a significant impediment to peace between Syria and Israel either, nor between Lebanon and Israel once a deal with Syria is in place. Such circumstances were impossible to imagine even as recently as 1990.

"Virtual water"

Advocates of political ecology theories contend that the environment, including water resources, is managed in the interests of the powerful. In the Jordan Basin, power relations have been explicit. Since 1948, Israel has achieved a hegemonic position in military terms. Without explicitly aiming to take control of the basin's water resources, Israel has nonetheless gained sovereignty over these resources in the upper Jordan Basin as a result of territorial expansion and military supremacy.[20] Integral to the politics of natural resources is the construction of knowledge to reinforce the position of the more powerful riparian state.

There is a long tradition of constructing knowledge about the water resources in the Jordan Basin countries. Political ecology theory explains the approaches taken by authors of the thirty or more books about water in the Jordan Basin. Lowdermilk's 1944 study had the clear agenda of justifying a Jewish claim for the regional water resources.[21] That of Ionides in 1953 was inspired by concern for the sustainable use of the limited water resources for economic and social purposes.[22]

In the Jordan Basin, as elsewhere, there has been a tendency to assume that water resources would determine economic outcomes and would have a significant and predictable impact on the international relations of riparian states. Armed conflict was presumed to be an unavoidable element in riparian relations. Yet toward the end of the century, the economic experience of the Jordan Basin has been a spectacular demonstration that natural resources such as water do not determine socio-economic development; on the contrary, socio-economic development determines water management options.

The assumption that local water would be the basis of economic and strategic security has underpinned hydropolitical discourses in all of the riparian states. They ignored growing real water deficits because recognizing such acute water shortages was politically too risky. Awareness of rising grain imports, which were the obvious indicators of increasing water deficits, could be kept out of the debate on water policy because they arrived invisibly and silently. By 2000, grain imports to Israel (including Palestine) and Jordan exceeded five million tons annually.[23] Had all available freshwater resources in the three territories been exclusively earmarked for grain production, the combined efforts of the Jordan Basin riparian states would only have yielded roughly three million tons of grain.

The international market for grain is immensely flexible and an extraordinary phenomenon of political economy. Yet it is by no means an optimising market system. In fact, its workings are extremely irrational economically.[24] The Jordan Basin countries benefit from the low world grain prices, which are a direct result of years of subsidized agriculture in Europe and North America. Though branded as perverse by economists, agricultural policies in the West nonetheless enjoy broad political support. More importantly, these subsidized grain exports enable Middle Eastern governments to continue preaching "sanctioned discourses," namely that serious water deficits have yet to occur. The growing water deficits over the course of four decades are conspicuously absent from public debate, and the urgency posed by increasing water scarcity in the region has consistently been downplayed.

These perceptions of water in the region, conditioned by the international trade in virtual water, have adversely affected the prospect of successful water negotiations. Indeed, the complex economic processes that enable virtual water to meet local water deficits have been ignored, even though it allows for equitable use of limited freshwater advocated by international lawyers.[25] But the political imperative of maintaining familiar approaches based on conventional constructed knowledge continue to dominate negotiating agendas.

Negotiations toward a basin-wide agreement

Progress toward a basin-wide set of water agreements appeared to be at an advanced stage by 1995. The Israel-Jordan Peace Agreement, followed by the Oslo Accord in 1995, and then by apparently promising talks between Israel and Syria, made it appear that a new era had dawned. However, the assassination of Israeli Prime Minister Yitzhak Rabin in 1996 and the subsequent change of government in Israel reversed the progress toward a set of comprehensive agreements, including those over water. The 1996 reversal is an emblematic example of the tendency highlighted by Mayer that negotiators face much more trenchant, in this case lethal, opposition from the factions at home than they do from across the negotiating table:

> When nations negotiate, often the toughest bargaining is not between nations but within them. The reason is simple: international agreements, no matter how much in the national 'interest,' inevitably have differential effects on the factional concerns...experienced negotiators almost invariably insist that the more difficult part of their job consists not in dealing with the adversary across the table but in handling interest group, bureaucrats, and politicians at home.[26]

The articles in the September 1994 Peace Agreement between Israel and Jordan demonstrated in a classic way the significance of linkages. Jordan apparently obtained two hundred million cubic meters of water per year in tranches of fifty million cubic meters. The first two concessions were relatively uncomplicated and involved Israel's release of the water to Jordan. The second concession also involved some investment in Jordan. The last two negotiated water transfers were severely entangled in conditions of joint investment, which have made them difficult to realize because Jordan was (and remains) short of financial capital for infrastructure projects.

However, the most serious deficiency in the water articles of the Jordan-Israel Peace Agreement was the absence of any provision for drought circumstances. The recurrence of drought in the Jordan Basin is certain. In the event of a drought, freshwater availability should be negotiated by clearly distinguishing reliable sources of water from unreliable ones. Reliable sources of water are those that will be available every year irrespective of drought, provided that surface water and groundwater resources have been managed sustainably. Unreliable water resources are only available in non-drought years. Negotiators always simplify the situation by choosing tentative numbers as if all the water were reliable. Within four years of the 1994 agreement, a serious drought had exposed this unfortunate assumption. Israel's failure to deliver the negotiated volume was so highly charged politically that the issue quickly went to the King of Jordan and senior Israeli cabinet members for resolution.[27]

The most recent water negotiations occurred during the July 2000 session at Camp David and at Taba the following year. These meetings merely emphasized the low priority given to water disputes in relation to the more symbolic issues of Jerusalem and territory. The more recent Saudi proposals of March 2002 ignored water entirely. The Saudi proposal was to extend recognition to Israel by twenty-two Arab governments in exchange for a return to 1967 borders and consideration of the position of Palestinian refugees.

These recent peace plans should not be interpreted as a sign that water has become unimportant to either side. If anything, the establishment of the Joint Water Committee (JWC), an institution associated with the Oslo Accord, underscores the importance each side confers on water issues. The JWC continues to hold regular meetings—even during the height of the second *Intifada* in 2001 and 2002. In January 2001, a joint statement by the Israeli Water Commissioner and the head of the Palestinian Water Authority called on both sides to avoid damage to the water infrastructure and interference with water supplies.[28] At the same time, the Joint Water Committee is a source of frustration to Palestinian professionals as it is subject to the Israeli Defense Force views on security. Nevertheless, water management throughout the 1990s is a testament to the possibility of cooperation over this important strategic resource, and ensures that water will remain high on the agenda in both Palestine and Israel, despite the overwhelming social and security disruptions since September 2000.

Water resources in the twenty-first century Middle East

By the year 2000, a number of phases of Israeli immigration and natural population growth in Jordan, Gaza, and Syria had increased population within the basin to over fifteen million. Freshwater resources have not increased beyond the three billion cubic meters per year available in the 1950s. Soil water resources also remain unchanged. Water resource requirements for self-sufficiency, including food requirements, have risen to fifteen billion cubic meters annually. Some would regard this as a low estimate, especially as standards of living increase. Others would also correctly argue that it would not be possible to close down all irrigated farming. Even the three billion cubic meters of freshwater available annually is not, therefore, a secure level for the non-agricultural demands of current and future populations. Clearly, the populations of the basin currently need between four and five times the freshwater to which they have access, soil water being a negligible element in the water balance. The significant amounts of freshwater required to meet the growing food needs of the basin's populations can only be accessed via international trade in virtual water.

The relatively small amounts of water needed for domestic and industrial use—only 10 percent of the total required for self-sufficiency—are much less of a challenge. Indeed, desalination technology holds great potential for adequately supplying non-agricultural water demand. Israel had delayed installing desalination capacity, judging that the period after a peace agreement with Palestine would be the best circumstances in which to announce its desalination program. However, with the deterioration in relations with Palestine after the July 2000 Camp David meeting and the onset of a drought, Israel brought forward its program and announced in November 2001 its first plant with a capacity of fifty million cubic meters per year. A second plant was announced in spring 2002, adding another fifty million cubic meters per year in desalination capacity. These were part of a planned four hundred million cubic meter capacity. Construction of two plants to produce a total of one hundred million meters of water annually began in 2002. Ariel Sharon, as Infrastructure Minister in 1998, suggested that Israel would desalinate up to eight hundred million cubic meters per year within the first decades of the twenty-first century. The economies of the Jordan Basin are likely to be desalinating between one billion and 1.5 billion cubic meters of water by 2020. These volumes of high quality water would increase the currently available levels of freshwater by 50 percent. Many Israeli water professionals have realized that manufacturing water will be much easier than negotiating it. Indeed, it will be less complicated and more secure to manufacture water than to depend on its ongoing provision by hostile neighbours, even if legal entitlement or a negotiated entitlement could be achieved.

The rapid changes in Israeli water management and allocation policies confirm that water can easily become a politicised issue. Such shifts in national policy have a profound impact on the negotiating positions adopted by contending riparians. Any understanding of national and international water in the Middle East region can only be achieved by examining closely the driving political forces that generated particular environmental, technological, and especially economic policies. However, it is the global trading system that provides the strongest explanation for the water policies adopted by the Jordan Basin riparian states. Virtual water enables serious water deficit economies to solve their water problems inexpensively, invisibly, and without political cost. More importantly, global trade enables Middle Eastern political economies to construct false but widely accepted notions of water security and to reinforce politically comfortable but economically and environmentally very sub-optimal water allocation policies. The sub-optimising role of virtual water is that its availability slows the adoption of much needed water policy reform. Necessary but politically difficult measures—especially reforms enabling more efficient water allocation—which would achieve higher returns on scarce water assets, are avoided because of the perceived political costs of introducing them. The first decades of the twenty-first century will be subject to the same ideas as those that shaped water policy and negotiating positions in the previous half-century. Politics will also continue to dominate the water sectors of individual political economies as well as waters that are shared internationally.

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10

The role of public policies in motivating virtual water trade, with an example from Egypt

D. Wichelns

Abstract

Public policies regarding the economy, international trade, and the prices of inputs and outputs influence farm-level decisions regarding crop production and marketing. National efforts to implement a virtual water strategy will have a greater likelihood of success if the impacts of public policies on farm-level decisions are considered when designing policies to encourage changes in farm-level management of land and water resources. Pertinent policies include those that modify the prices of agricultural inputs and outputs, either directly or indirectly, and those that define the allocation of scarce resources among sectors of the economy and among individual firms or consumers within sectors. Governments also may gain by considering the broad set of national goals regarding agriculture, employment, poverty reduction, and food security, when designing policies to support a virtual water strategy. Data describing agricultural production and international trade in grains and cotton for Egypt are reviewed to gain insight regarding the influence of public policies on farm-level decisions, aggregate production, and trade patterns.
The Role of Public Policies in Motivating Virtual Water Trade, With an Example from Egypt

1. Introduction

Professor J.A. Allan has defined ‘virtual water’ as the water embodied in food crops that are traded internationally (Allan, 1996a,b, 1998). The concept of virtual water is helpful in describing a water-short nation’s opportunities for achieving food security by purchasing a portion of its food requirements in international markets, rather than using scarce water resources to produce all of the food crops consumed each year. A virtual water strategy is particularly pertinent in years when the world prices of food grains are lower than the costs of production in water-short countries.

The virtual water concept is closely related to the notion of comparative advantage from international trade theory (Allan, 1999; Earle, 2001; Wichelns, 2001). In essence, countries can enhance the total value of goods and services available to residents by exporting products for which the country has a relative or comparative advantage in production, while importing products for which the country has a comparative disadvantage. For example, countries in water-short regions may gain from trade by importing water-intensive crops, while using their limited water supply for activities that generate greater incremental values. Professor Allan (1998) describes the role of international trade in moving virtual water from “comparatively advantaged regions, where there is a surplus of soil water in soil profiles to comparatively disadvantaged regions such as the MENA region (Middle East and North Africa), where water is scarce.”

In arid regions where a limited water supply constrains economic activity, national governments can enhance economic growth and development by adopting policies that enable or promote international trade patterns that reflect water scarcity. The virtual water concept may be helpful in describing the potential gains from trade and in identifying specific production and marketing opportunities that will enhance economic development (Yang and Zehnder, 2002). However, the virtual water concept is not, by itself, an operational programme. Nations wishing to pursue a virtual water strategy with respect to agricultural production, industrial development, and international trade will need to identify public policies that motivate farmers and other entrepreneurs to choose production and marketing activities consistent with that strategy.

The goal of this paper is to examine the potential impacts of public policies on farm-level decisions regarding crop production and marketing, with particular emphasis on a nation’s efforts to implement a virtual water strategy.

Pertinent policies include those that modify prices of agricultural inputs and outputs, either directly or indirectly, and those that define the allocation of scarce resources among sectors of the economy and among individual firms or consumers within sectors. The paper is motivated by the hypothesis that policies which influence farm-level decisions can have a substantial impact on the likelihood that a nation's efforts to implement a virtual water strategy will be successful. Data describing agricultural production and international trade in grains and cotton for Egypt are reviewed to gain insight regarding the influence of public policies on farm-level decisions, aggregate production, and trade patterns.

2. Public policies and farm-level decisions

In most of the world's large agricultural regions, farmers choose crops and production practices based on their expectations of input and output prices, resource endowments, human capital, household needs, and other considerations. Only in rare cases, do national governments impose crops and production practices on farmers. One such case is the Gezira production system in Sudan, where the national government determines the mix of crops to be grown each year, the methods of production, and the levels of key inputs, such as water, fertilizer, and pesticides. In that setting, farmers largely are implementing the government's annual programme of crop production and marketing. They are not making economic choices regarding inputs and outputs. In such a setting, the government could implement a virtual water programme rather easily by imposing its wishes regarding production and marketing alternatives on the farmers. In most other production settings, however, governments do not play such a direct role in farm-level decisions.

When farmers choose crops and production practices independently, governments influence those choices through public policies that modify the farm-level prices of inputs and outputs, the availability of key production resources, and farm-level access to marketing alternatives. For example, government policies that provide irrigation water to farmers at subsidized prices encourage the production of water-intensive crops, all else equal. Government policies that raise the exchange rate for a nation's currency above its true market value discourage farmers from growing crops for sale in export markets. An over-valued exchange rate makes exports more expensive to potential buyers, while imports become more affordable. Such a policy may discourage farmers from producing cotton for export, while also encouraging them to produce a nontradable crop that requires a large amount of imported fertilizer.

Governments can have a substantial impact on farm-level decisions through policies that restrict farm-level marketing options. Many governments in the developing world extract tax revenue from agriculture by requiring farmers to sell a portion of their output of selected crops to state or national marketing agencies, rather than allowing them to sell that portion in a true market setting (Hassan et al., 1992; Kherallah et al., 2002). Revenue is extracted when the marketing agency returns only a portion of its sales revenue to the farmers furnishing the crops. Government procurement schemes can discourage farmers from choosing crops that might be profitable if farmers were allowed to sell their output in a market setting. Many of the structural adjustment programmes implemented in developing countries since the middle 1980s have sought to eliminate government procurement schemes. However, some schemes still exist, particularly for tradable crops such as cotton and maize (Kherallah et al., 2002, p. 6).

Governments wishing to implement a virtual water strategy may face unexpected challenges if current agricultural or macroeconomic policies encourage farmers to select low-valued, water-intensive crops, rather than higher valued, tradable crops. As noted above, farm-level decisions regarding crops and marketing strategies are based largely on farm-level goals and parameters, and are not based directly on national objectives. In arid regions, where the opportunity cost of water may be substantial, farmers will choose to produce water-intensive crops if the farm-level price or availability of water does not reflect its scarcity value.

Policies regarding complementary inputs also can have a substantial impact on farm-level production decisions. For example, a public policy that provides electricity to farmers at a subsidized price will encourage them to use greater amounts of groundwater than they would use in the absence of the subsidy, all else equal. An electricity subsidy also may encourage production of water-intensive crops in an arid region where groundwater is required for irrigation.

The sources and farm-level availability of financial credit often are influenced by public policies, either through the setting of macroeconomic parameters such as interest rates or through the active involvement of a state or national agency in the production or sale of key inputs. When farmers cannot obtain affordable credit for purchasing seeds, fertilizers, and pesticides, they will choose to produce crops that require relatively small amounts of those inputs, all else equal. Public policies that enhance the farm-level availability of credit can encourage farmers to produce tradable crops that require substantial expenditures on inputs, to generate the quality required for sale in export markets. In the absence of affordable production loans, farmers will tend to choose nontradable crops that require fewer purchased inputs.

3. Public policies and virtual water trade in Egypt

Egypt is an arid nation that derives most of its water supply from the Nile River. Nearly all agricultural production requires irrigation, given that the mean annual rainfall ranges from zero mm in the desert to 24 mm in Cairo and 200 mm in the northern coastal region (Ward, 1993; FAO, 1997). The mean annual rainfall in the Nile Delta is 150 mm. The demand for water in agriculture, industry, and municipal uses has been increasing in Egypt due to population growth and increases in aggregate income. The current population of nearly 70 million is growing at an estimated 1.8% per year and is expected to exceed 90 million by 2020 (UNDP, 2002). Egypt's economy grew by nearly 5% per year during the 1990s and its gross national product per capita rose to about $1,500 in 2000 (World Bank, 2001a).

The annual supply of water in Egypt is determined largely by its agreement with Sudan that allows Egypt to use 55.5 billion m^3 of Nile River water each year. The Egyptian water ministry augments that volume by capturing and recycling agricultural drainage water (Abu-Zeid, 1993; Kheireldin and Tawfik, 1997). At present, the total volume of water available each year is sufficient to satisfy aggregate demand (Simonovic et al., 1997). However, periodic droughts, regional shortages, localized capacity constraints, and inequitable sharing of water along canals reduce irrigation opportunities in some regions of the country (Stoner, 1994; Radwan, 1997; Hvidt, 1998). Hence, improvements in water management and distribution will enhance aggregate production and contribute to the national goals of reducing poverty and maintaining economic growth and development.

Agriculture accounts for less than 20% of Egypt's gross domestic product, while providing about 30% of total employment (World Bank, 2001a, 2001b; EIU, 2002). The socioeconomic importance of agriculture is larger than its proportion of GDP might indicate. Agriculture accounted for about 13% of Egypt's non-oil exports in the 1990s, but if processing activities are considered, that proportion rises to 53% (World Bank, 2001b). In addition, more than half of Egypt's population is rural. Hence, improvements in the performance of the agricultural sector may contribute substantially to alleviating poverty and enhancing food security in rural households.

Food security at the national level in Egypt is achieved through a combination of domestic production and imports of agricultural products. The estimated average daily food supply is 3,346 kilocalories per person (kcal/p/d), of which 3,090 and 256 kcal/p/d are obtained from vegetable and animal products, respectively (FAO, 2000). Wheat, maize, and rice are the primary food crops, accounting for 1,098, 557, and 410 kcal/p/d. The per capita supplies of wheat, maize, and rice in Egypt have increased substantially since the 1960s (Figure 1), even though the population has grown from about 30 million to 70 million during the same time period. Those increases have been made possible by improvements in agricultural technology, policy reforms that have encouraged farmers to enhance productivity, and increasing imports of wheat and maize.

Imports of food and fodder crops, and the virtual water contained in those crops, have contributed to Egypt's ability to maintain aggregate food security since the 1960s. However, Egyptian farmers also produce large amounts of water-intensive and low-valued crops for both domestic production and export. Hence, virtual water is imported and exported from Egypt through its involvement in international trade. The complex nature of virtual water trade and the potential impacts of public policies on farm-level decisions are demonstrated by reviewing empirical information describing Egyptian agricultural production, imports, and exports since the 1960s. Policy implications are derived after reviewing data pertaining to wheat, maize, rice, and cotton.

Wheat and Maize

Domestic production of wheat and maize has been increasing somewhat sharply since the middle 1980s. In particular, the rates of increase in domestic production since 1986 are notably higher than the rates observed during

1962 through 1985 (Figure 2). The faster rates of increase observed in recent years likely are due, in part, to policy changes that have allowed Egyptian farmers greater freedom in choosing crops and in selling their produce in competitive markets (Nassar et al., 1996; Abdel-Latif et al., 1998). Wheat yields per hectare increased by an average rate of 3.7% per year between 1980-84 and 1992-96 (Adams, 2000). Farm-level returns to wheat and maize production improved in the 1990s, due partly to government policies that protected poultry and livestock production (World Bank, 2001b, p. 30.), while net returns to cotton production were still limited by government restrictions regarding production and marketing options (Okonjo-Iweala and Fuleihan, 1993; Khedr et al., 1996). Land reclamation programmes also contributed to the increase in wheat and maize production observed in the 1990s (Shousha and Pautsch, 1997).

Wheat imports increased from about one million tonnes in 1962 to more than 7 million tonnes in 1998, before declining to about 5 million tonnes in recent years (Figure 3). At one time in the 1980s, Egypt was the third largest importer of wheat after China and Russia (Weiss and Wurzel, 1998). Maize imports have increased from less than 1 million tonnes in 1962 to more than 3 million tonnes annually, since 1997 (Figure 4). Much of the imported wheat is used to produce bread and flour that are distributed in food subsidy programmes, while the imported maize is used to feed livestock (Alderman, 1993: Ward, 1993; Gutner, 1999).

Rice and Cotton

Domestic production of rice in Egypt was relatively stable for more than 20 years, before increasing sharply after 1988 (Figure 5). Since that year, production has risen from about 1.5 million tonnes of milled equivalent to 4.0 million tonnes in 2000. This sharp rate of increase is consistent with the trend observed for wheat and maize (Figure 2) and likely is due also to changes in government policies that have enabled farmers to earn greater net returns from rice production.

Domestic production of cotton in Egypt generally has been declining since 1980, although production has increased above the declining trend in some years (Figure 6). The period during which cotton production has been declining coincides generally with the period during which the domestic production of wheat, maize, and rice has been increasing. Farm-level incentives to increase cotton production were limited by the government's policy of paying farmers less than one-half the international price for their output (Baffes and Gautam, 1996).

Most of the rice produced in Egypt is consumed domestically, while a small but increasing proportion of the crop is exported (Kotb et al., 2000). Rice exports have risen from very small amounts in the 1980s to more than 300,000 tonnes in recent years (Figure 7). Cotton exports, which historically have been an important source of foreign exchange in Egypt, declined from 203,000 tonnes of lint in 1983 to just 13,000 tonnes in 1991 (Figure 8), due primarily to changes in agricultural policies and government decisions regarding the allocation of cotton between domestic and international markets (Khedr et al., 1996). Cotton exports have remained below 70,000 tonnes annually since 1991, with the exceptions of 1994 and 1999.

4. Discussion

An examination of the virtual water concept within the context of Egypt's experience since the 1960s provides insight regarding the role of imports and exports in achieving national food security and the impacts of public policies on farm-level decisions regarding crop production and marketing alternatives. Egypt imports substantial volumes of virtual water each year with its imports of wheat and maize. Domestic water use also has increased substantially, over time, with large increases in the production of wheat, maize, and rice. Egyptian exports of rice have increased in recent years, while cotton exports have remained far below the levels observed in the 1960s and 1970s.

Increases in the production and export of rice, in combination with declining exports of cotton might appear to be inconsistent with a virtual water strategy to maximize the value of Egypt's limited water supply. However, it is possible that both rising domestic production and rising imports have been needed to achieve food security, given the large rate of population growth in Egypt since the 1960s. Increases in domestic production of food and fodder also may have been essential in improving incomes, reducing poverty, and enhancing household food security in rural areas. In addition, public policies that influence farm-level decisions have encouraged farmers to produce food and fodder crops, rather than cotton, even though cotton may generate greater returns per unit of water.

Farm-level choices are influenced also by farm-level resource constraints. For example, farmers with a limited supply of land, but a relatively abundant water supply, will choose crops that maximize returns to land, rather than to water. Most farmers in Egypt have only small amounts of land available, while water is relatively abundant. The national average farm holding is about one hectare of land (Hopkins, 1993), while farm-level water use in many areas is not constrained. Most irrigation water deliveries in Egypt are not measured, allocated, or priced by volume. In many areas, farmers can obtain sufficient water to support the production of two or three crops per year on all of their land. In other areas, such as the tail ends of secondary and tertiary canals, farmers must use saline water from surface drains to augment the volume of freshwater available. In those areas, water is relatively abundant in the near-term, although land quality is degraded over time due to increasing soil salinity. In all areas where land is scarce, relative to the available water supply, farmers will choose crops that generate the largest farm-level net benefits per unit of land, rather than per unit of water.

5. Policy implications

Food security at the national level has been achieved and maintained in Egypt by increasing the production of crops and livestock products within the country and by importing food and fodder from other nations. Food consumption per capita has increased substantially in recent decades, even though population has increased by more than 100% since 1962. Egypt's population likely will increase from about 70 million in 2002 to more than 90 million in 2020, while the land and water resources available for agriculture will remain largely fixed. Hence, further improvements in agricultural production and even greater reliance on international trade may be needed in future to maintain current levels of food consumption and economic growth.

Policies that encourage farmers to acknowledge the scarcity value of Egypt's limited water supply will gain importance in future, both to ensure that water is used efficiently in domestic production and to motivate production of high-valued crops for export. The gains that can be achieved by focusing on production activities for which Egypt has a comparative advantage will increase with increasing resource scarcity. Farm-level decisions regarding inputs and outputs will be consistent with national goals if the farm-level prices or allotments of water and other resources reflect the relative scarcity of those resources.

Increased production of higher-valued, tradable crops may generate substantial benefits for Egypt, in addition to the water savings that may result by reducing the area planted in rice. Egypt has a comparative advantage in cotton production, and it has a long history of exporting raw cotton and textiles. Efforts to increase cotton production and to expand the textile sector may be very helpful in reducing water diversions from the irrigation system and in generating new jobs in rural and urban areas. The textile industry in Egypt employs 500,000 workers, or about 25% of all employment in manufacturing (Henry and Springborg, 2001, p. 143). The total value of output and the sector's contributions to export earnings declined in the 1990s (World Bank, 2001b), but output values, exports, and employment opportunities might be enhanced in future with improvements in management and investments in modern technology.

The value to Egypt of increasing employment opportunities may exceed the value attributed to water savings, particularly in the near term, given the current rate of unemployment and the broad base of Egypt's population structure. The current aggregate rate of unemployment in Egypt likely is between 8% and 12%, although higher rates are reported for some governorates (EIU, 2002; Radwan, 2002; UNDP, 2002). Estimates of the number of new entrants in the labor market each year range from 638,000 to 896,000, while the domestic economy generates only an estimated 435,000 jobs, and an estimated 90,000 persons emigrate each year (World Bank, 2001a; Radwan, 2002). Thus, the estimated number of additional jobs needed each year ranges from 113,000 to 371,000. The size of the labor force in Egypt may increase from 22 million individuals in 1996 to 32 million individuals in 2020 (Rivlin, 2001, p. 35).

The excess supply of labor in Egypt has contributed to a decline in real wages in many sectors of the economy. The index of real wages in Egypt declined from 100 in 1985-86 to 68.6 for agriculture and 68.4 for industry in 1994-95 (Adams, 2000). This broad decline in real wages has contributed to an increase in poverty in both rural and urban areas. Livelihoods in rural areas have been impacted also by implementation of Law 96 of 1992, which has ended the security of tenure for tenant farmers and enabled landowners to charge rents that reflect market values of farmland (Bush, 2000). Prior to implementing the new law, rents had been constrained for many years at levels below true market value. Higher rents and the loss of tenure may cause smallholders to lose their farming operations and to seek alternative employment opportunities.

National issues and goals regarding employment levels, poverty reduction, and the provision of food subsidies for poor residents in Egypt should be considered when evaluating policies to encourage wiser use of the nation's limited water resources. Recent changes in farm-level incentives and access to resources will influence farm-level responses to new policies regarding land and water resources. In addition, remaining constraints on the production and marketing of cotton will continue to influence farm-level decisions regarding cropping patterns and input use. Subject to such considerations, the following policies may be helpful in encouraging farmers to consider the scarcity value of water in Egypt and to consider switching from water-intensive, low-valued crops to higher valued crops that require smaller diversions of irrigation water:

- Implementing charges for irrigation water deliveries on a per-hectare basis, such that the price per hectare is higher for crops with larger water requirements (land area pricing),
- Implementing charges for irrigation water deliveries that increase with the volume of water delivered (volumetric pricing),
- Allocating water among farmers to prevent headend farmers from diverting excessive volumes of water, while causing shortages in tailend reaches of secondary and tertiary canals (an alternative to water pricing),
- Removing any restrictions on crop production and marketing choices (allowing farmers to sell cotton and other crops to private sector buyers),
- Ensuring that the nation's currency exchange rate is not supported above its true market value,
- Enhancing farm-level access to short-term and long-term loans that may be needed to modify production practices (enhancing microcredit),
- Enhancing farm-level access to key production inputs, such as the fertilizer and pesticides that may be needed to produce higher valued crops, and
- Providing farmers with training programs to enhance their ability to produce alternative crops and to use limited resources efficiently.

Implementing one or more of these policies will enhance the likelihood that farmers will choose crops and production practices that are consistent with a national goal of increasing the values generated with limited water resources. None of these policies represents a sufficient condition for motivating rapid adoption of production patterns that are consistent with a national strategy to increase imports of virtual water. However, one or more of the policies might be viewed as a necessary condition. In particular, as long as some farmers perceive that irrigation water is a relatively abundant resource, they will not be motivated to switch to crops that use less irrigation water. In addition, as long as farmers perceive that their marketing options and net returns to cotton production may be limited by a government procurement program, they will not be encouraged to switch from growing rice to growing cotton. In summary, national efforts to increase the values obtained from both real and virtual water will be enhanced by acknowledging the impacts of agricultural and macroeconomic policies on farm-level decisions.

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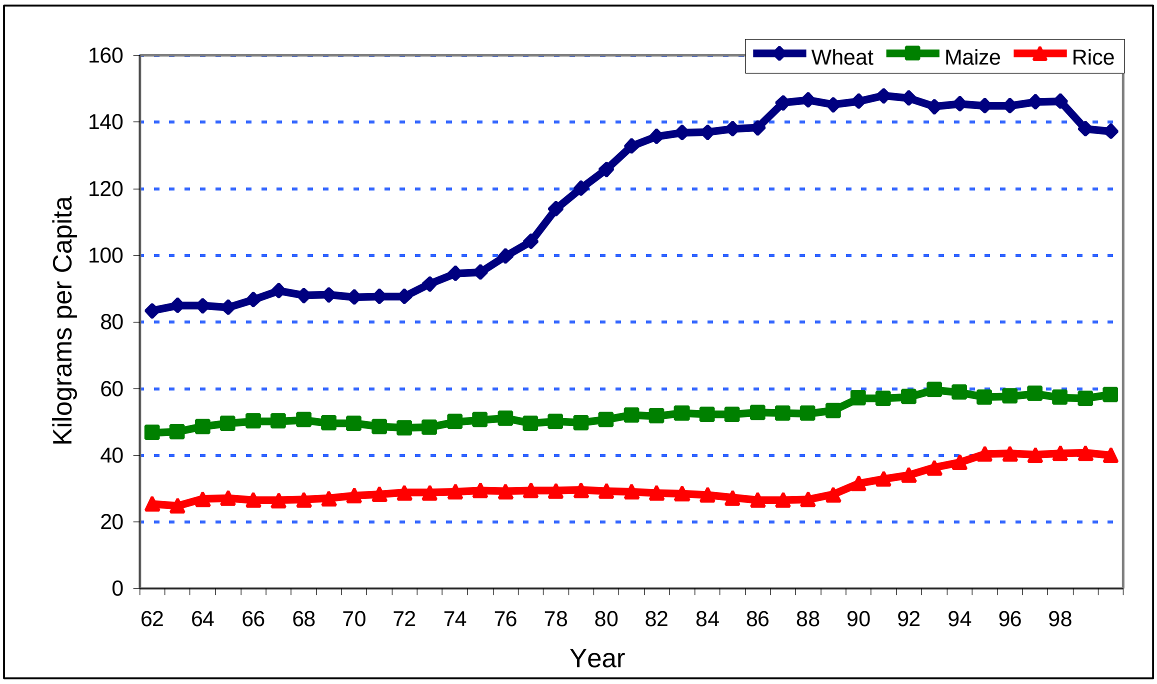

Figure 1. Per capita food supplies in Egypt, 1962 to 2000.

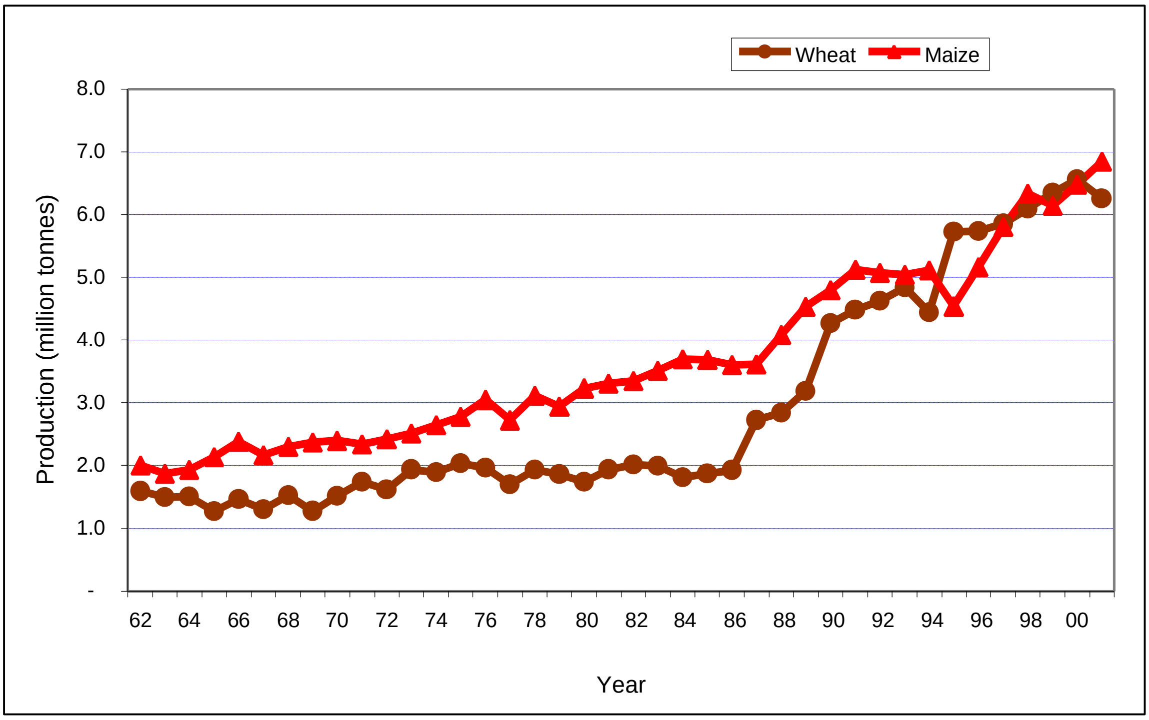

Figure 2.Production of wheat and maize in Egypt, 1962 to 2000.

Figure 3. Wheat imports to Egypt, 1962 to 2000.

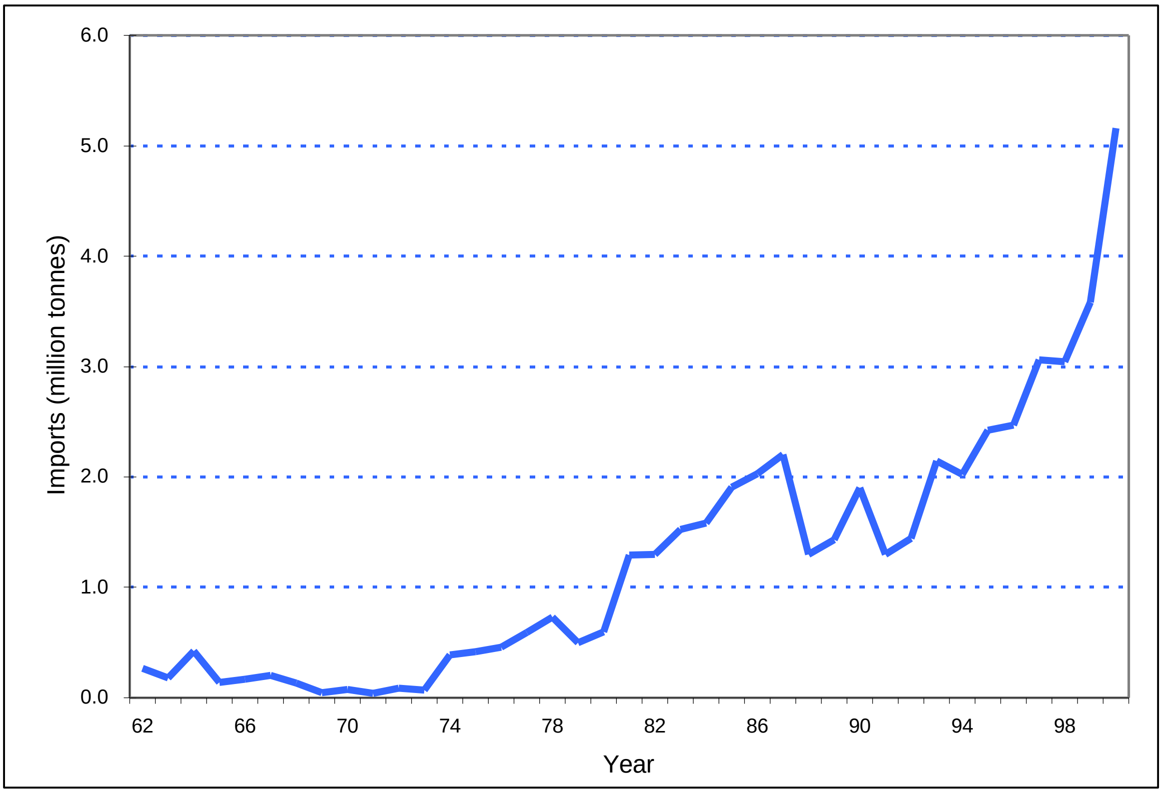

Figure 4. Maize imports to Egypt, 1962 to 2000.

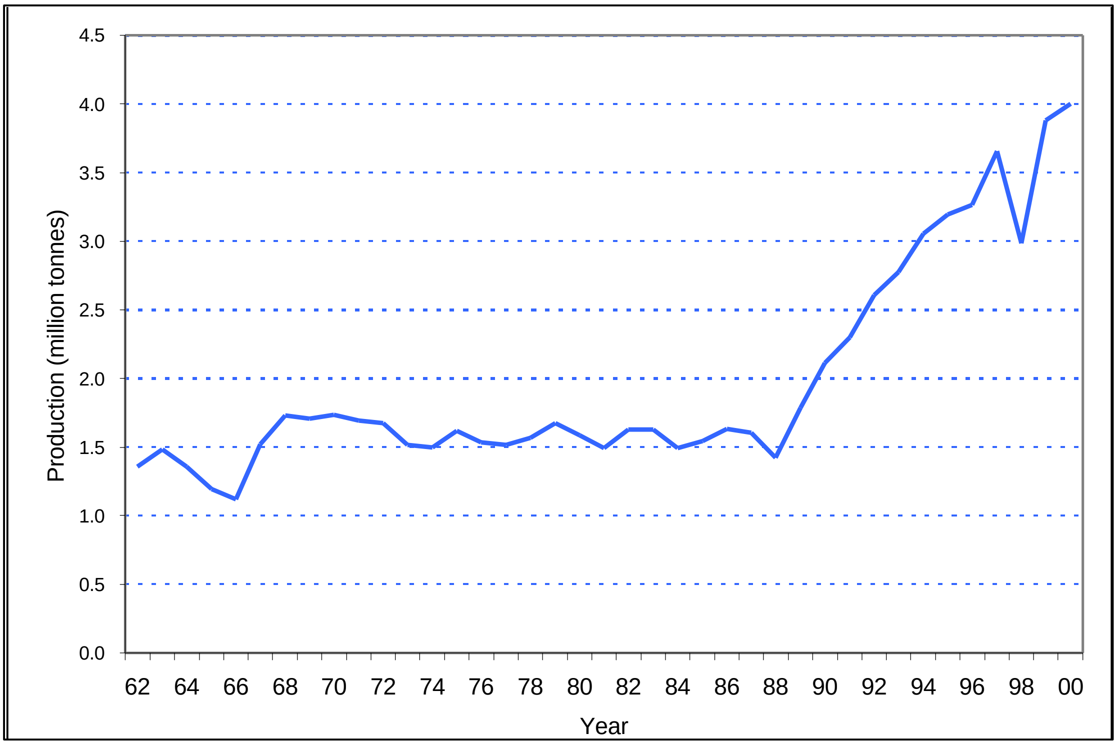

Figure 5. Production of rice in Egypt (in milled equivalents), 1962 to 2000.

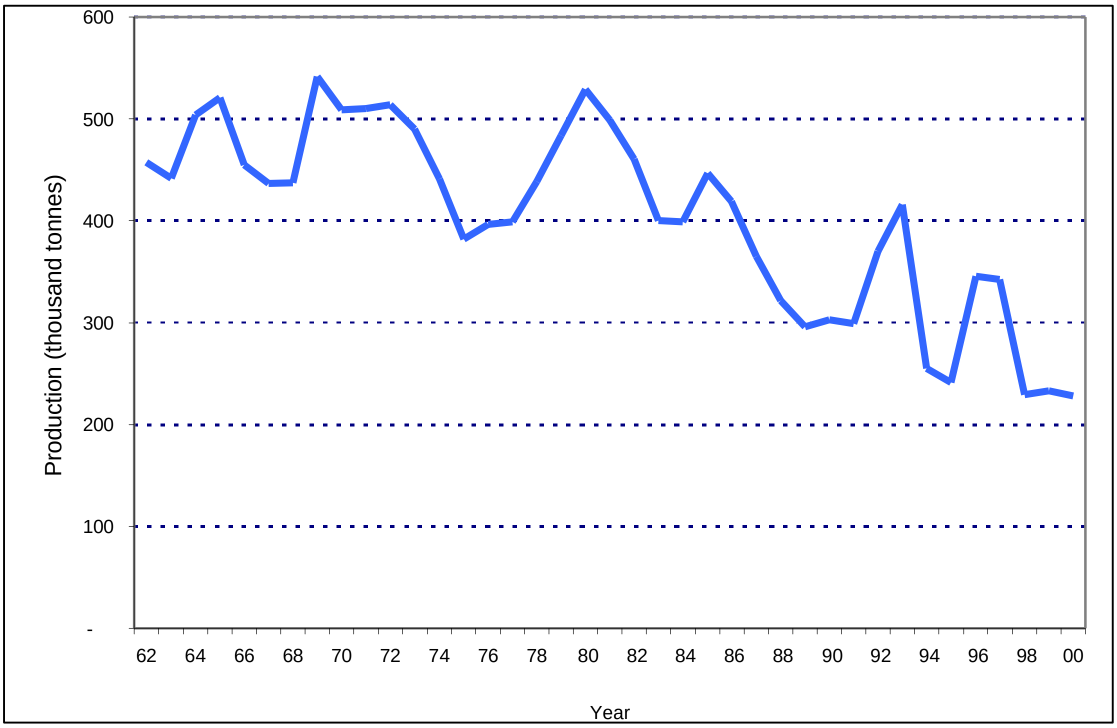

Figure 6. Production of cotton in Egypt, 1980 to 2000.

Figure 7. Rice exports from Egypt. 1962 to 2000.

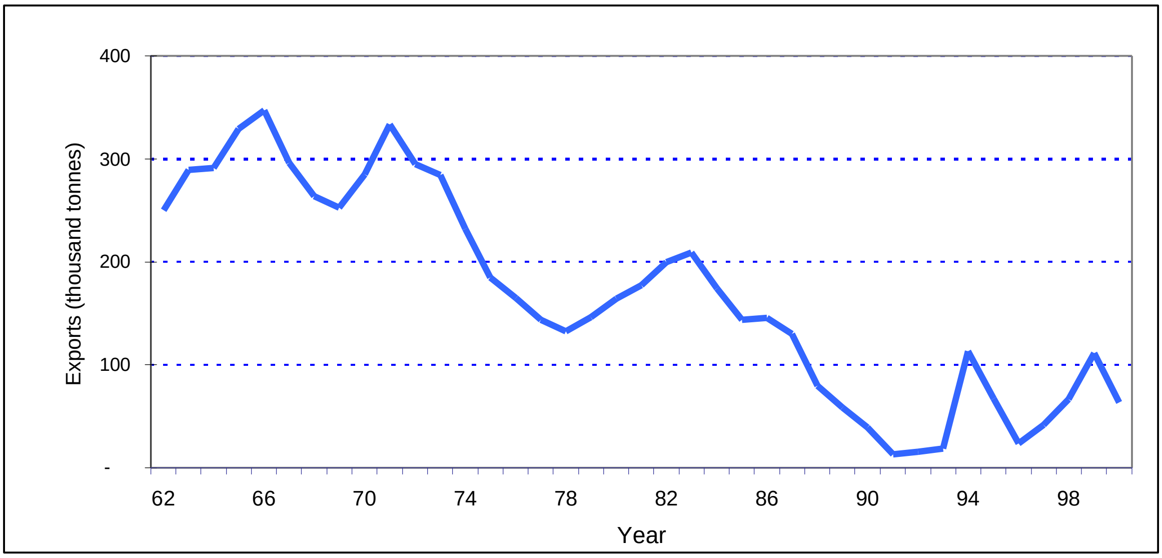

Figure 8. Cotton exports from Egypt. 1962 to 2000.

11

Exogenous water: A conduit to globalization of water resources

M.J. Haddadin

Introduction

Water, as is universally known, is used in agriculture to grow food, in municipal and industrial purposes, in hydropower generation, in environmental and recreational purposes and in transportation through navigation. We intend to stress the use in food production because of the high percentage that use claims of the total water resources, especially in countries of arid and semi arid regions, and because of the possibility of augmenting it or even totally replacing it with "imported water" in the form of food imports.

The quantitative determination of the needs for each of the above purposes is not an easy task; it involves the employment of judgments based on experience and data gathered by various authorities. In our approach in this paper, we focus on the municipal, industrial and recreational purposes, and on the production of food. Water needs to satisfy other purposes (hydropower, transportation, environmental…) are not included.

It is widely known that many countries, especially those located in arid and semi arid regions, have huge deficits in their water budgets, but that deficit is closed by food imports so that the agricultural water shortage is covered by exogenous water originating in the country of source of food imports. Because of the food trade facilities, water resources are globalized in the sense that water deficit countries can share water rich countries the wealth of their water stock through food trade.

We are familiar with a variety of phrases in the water literature. We intend to use them in as much as those relate to our topic. Among those phrases are:

- Virtual Water first introduced by Professor Tony Allan to mean the water that otherwise would be needed to produce the net food imports that a country brings in from the outside. Because of the expansion of use of the word "virtual", especially in high technology media, we suggest the use of "Exogenous Water" to carry the same meaning that Allan intended by the term "Virtual Water". This phrase should not be construed to include the portion of the indigenous water that a riparian is due as his share in international water courses. A riparian share is counted among the indigenous stock of water resources.
- Water Stress, usually used to describe the degree to which water resources are short of meeting the needs of the population of a given country. In our case we propose to define water stress as the number of people per unit flow of indigenous water; the unit flow of water being taken as one million cubic meters per year. As such, water stress has a quantitative value expressed in people per unit flow. This definition draws analogy from the science of engineering mechanics where the stress in a cross section of a bar as a result of an axial force acting on the bar is defined as the force per unit area.
- Water Strain, a phrase we introduce to mean the deficit in water resources divided by the water resources needed to satisfy the needs. If the water availability is W_A , and the total need for water is $W_{n,}$ the water strain is equal to $(W_A - W_n)/ W_n$, negative for shortage and positive for surplus. This definition ties in with the terminology used in engineering mechanics where the strain is defined as the elongation/shortening of the bar in our above example divided by its original length.
- Yield Point, a phrase we introduce to signify the level of water stress at which the smooth operations in a given society is disturbed, and its behavior becomes chaotic. In engineering mechanics, the yield point of an elastic material is the point beyond which strains (elongations) are induced without further stress.
- Again, drawing from the science of engineering mechanics, one notes that an elastic material exhibits a linear relationship between stress and strain up to its yield point. Beyond that point, the material elongates without any further stress. Figure 1 shows an idealized stress-strain relationship of an elastic material. The slope of the linear curve is called the Elasticity Modulus. It is constant for a given elastic material and is one of its characteristics.

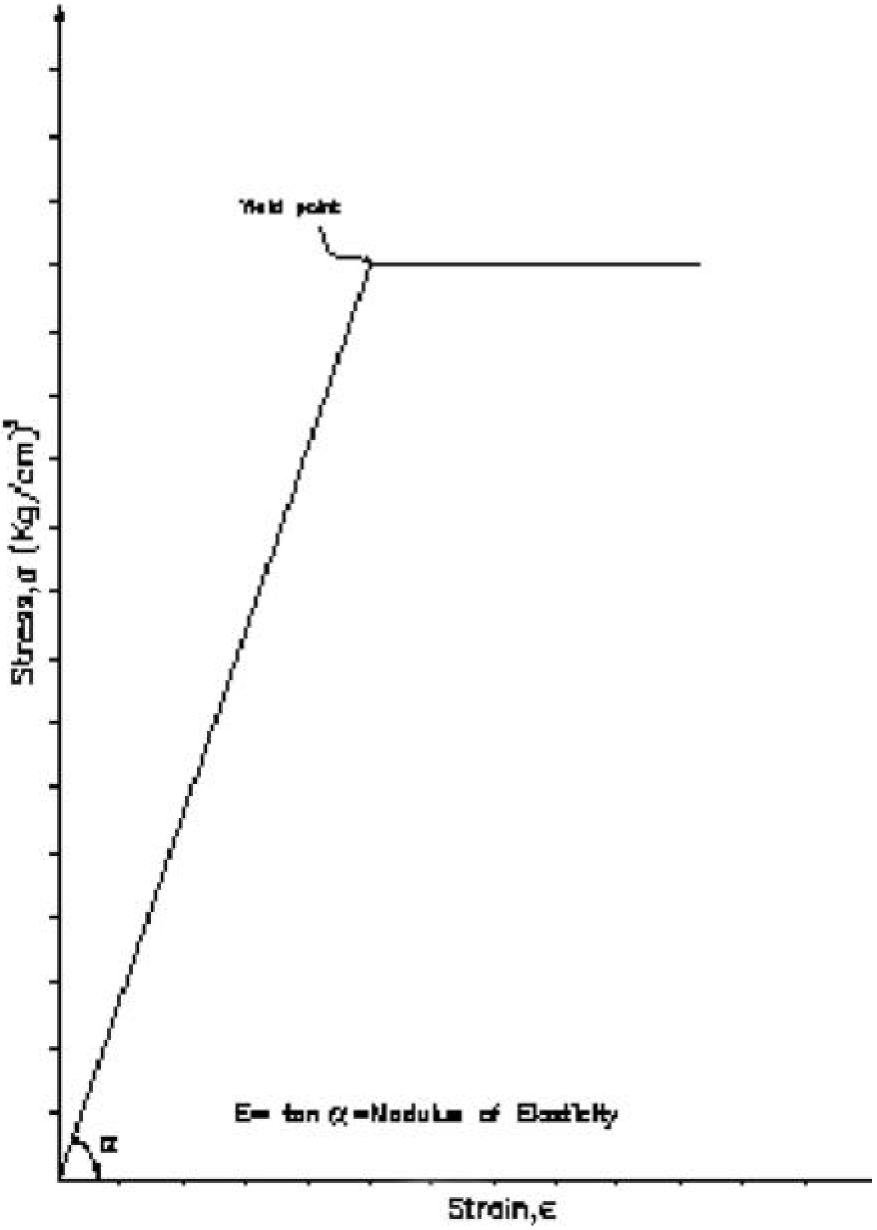

Figure 1. Idealized stress strain diagram.

Water budget and deficit

Water availability is the total sum of the indigenous and the exogenous (virtual) water resources. The indigenous water resources are composed of the flowing surface water, water stored in surface and ground water reservoirs, and in the soil profile, and moisture brought about by dew. In the preparation of the indigenous water budget, the indigenous water stock is the supply, and the consumption (including evaporation) represents the demand. Evaporation from soil surface claims a high percentage of the rainfall and part of the surface reservoirs exposed to the atmosphere. Available indigenous water resources are normally reported as the actual quantity net of evaporation from the soil surface and the reservoirs. Transpiration, however, is part of the consumption process.

Other factors impacting water availability for consumption are the efficiency by which water is conveyed from the source to the point of use, and the amount of water applied for use as compared to the exact amount needed for the purpose. Examples of the loss of water due to low conveyance efficiency are the losses incurred when irrigation water is conveyed through earth canals to the farm gate, and through furrows or ditches from the farm gate to the plant. Also leaky networks conveying municipal water are additional examples. Over-application of water for the intended uses is displayed by such practices as basin irrigation, running faucet water while shaving, running showers when the water is not needed, and the like. Examples of loss of water, indigenous or exogenous, are the quantities of spoiled food and food thrown to garbage, the over-eating habits of some consumers, and the like.

The deficit in the water budget is the difference between supply and demand. In this paper the supply consists of the renewable water resources, net of evaporation, the treated wastewater, and the soil water. The demand is the water needed for municipal, recreational and industrial purposes, and the irrigation water needed to produce food. As was mentioned in the above, exogenous (virtual) water closes the water budget deficits. Avoiding the deficits through food imports has an important pre-requisite which is the availability of foreign currency to finance the foreign trade in food and other basic necessities imported from the outside. This aspect is not addressed here, but we assume that there is enough supply of foreign currency to service foreign trade.

To compute the exogenous (virtual) water, one needs to determine the supply and the demand, and the deficit that would be incurred. The surface and ground water, along with the treated wastewater resources are usually reported by the official authority of the country. In this paper, we suggest an approximation for the measurement of the soil water irrigation equivalent to add to the supply part of the equation. The demand part is determined by placing values for the municipal, recreational and industrial water and to the irrigation water needed to produce food. The needs take account of the level of economic progress a society has achieved. In the case of the latter, the water needed to grow food under a totally irrigated agriculture environment is first computed, and an estimate shall be made of the irrigation equivalent of soil water as it is the contribution of rain fed agriculture to food production.

Water needs

Water needs for all purposes is a function of the standard of living of the subject society and the level of industrial progress that society has attained. In our study, we follow the economic categories of countries adopted by the World Bank; i.e, Low, Lower Middle, Upper Middle and High income economies as indicative of the standard of living and a base for the computation of the per capita requirement for water. The economic categories are also taken to indicate the level of water conveyance efficiency and the food consumption requirements. A major factor in determining the water needs is the policy dopted in a given country regarding government treasury subsidies to the cost of water, exogenous or indigenous. Government subsidies distort the water market and invite waste. In our analysis we assume that cross-subsidy, away from treasury contributions, is built in water tariffs only to help the poor segment of society whose water consumption is set at minimum levels.

As mentioned above, the water needs considered in this paper are the needs for municipal, recreational and industrial purposes and the needs for agricultural purposes to produce food. Below is the methodology followed in determining these needs and the assumptions made in the process.

Water for municipal networks

Municipal networks usually convey, along with municipal water, industrial water and recreational water. The flow of water needed in these networks differ with the different economic categories of countries.
A minimum of 50 liters per capita per day has been specified for subsistence. A judgment is made here to assign an average allocation at the point of use for inhabitants of the countries of the four income categories, and to assign values for the attainable levels of conveyance and distribution efficiency. An average allocation, including the over-use rate, of 200, 225, 250 and 300 liters per capita per day for municipal and recreational needs are assumed for the Low, Lower Middle, Upper Middle and High Income categories. To those, an average allocation of 20, 25, 25 and 30 liters per capita per day is added for industrial purposes. The total allocation per capita per day would thus be 220, 250, 275 and 330 liters for the four categories respectively. This is equivalent to 80, 90, 100 and 120 cubic meters per capita per year. The attainable conveyance and distribution efficiency for municipal water networks, a matter of judgment from experience, can be assumed at 65%, 70%, 75%, and 85% for the above income categories respectively. Thus the annual allocation to meet water needs for municipal, recreational and industrial purposes, measured at the water source, would be

$$M_m = M_1/E_1 \tag{1}$$

Where,
M_m is the amount of water, measured at the source, for municipal, recreational and industrial needs.
M_1 is the amount of water for the same purposes measured at the point of use, and,
E_1 is the overall water conveyance and distribution efficiency.

Table 1. Annual M_m water needs per capita, m^3.

Income Category	Quantity at Point of Use	Overall Efficiency	Quantity at Source
Low	80	0.65	123
Lower Middle	90	0.70	128
Upper Middle	100	0.75	133
High	120	0.85	141

Water needs for food production

An assessment of the water needs to produce the food per capita in a given country would be burdened with more uncertainties than precision would tolerate. For one thing, a country can not produce its entire food needs domestically for reasons imposed by climate zones in which crops would grow and yield fruit. Food trade between societies and countries has been known for ages, and people have adjusted their diets accordingly. It is known, for example, that the grain of the American Midwest is consumed in water short countries and it is not unusual to find on the markets of arid and semi arid countries of the Northern Hemisphere in December such summer fruits as watermelon, cantaloupe, and plums. Nor it is unusual to find in the markets of Rabat the Mangoes of Egypt or the bananas of Central America, and in Cuba the caviar of the Caspian Sea. The composition of the average diet in a country is projected herein with the assumption that free trade is practiced, the affordability of the average person is adequate to purchase the constituents of his assumed diet, and that the subject country's foreign exchange reserves and current accounts permit the imports of the food components. Table 2 (Elmusa, 1997) lists the composition of an average diet for a society of a Lower Middle Income Economy, and the amount of water needed to produce it.

Table 2. Composition of a food diet.

Item	Lower Middle Income (M.I)		
	Food Consumption (*kg/capita*)	Water Requirement (*m^3/100 kg*)	Water Demand (*m^3/ capita*)
Wheat	120	115-144	138-173
Rice	15	108-170	16-26
Sugar	35	125-200	44-70
Potatoes	25	14-22	4-6
Dry Pulses	7	167-330	12-23
Seeds (e.g., sesame)	2	200-500	4-10
Fresh Vegetables	150	20-22	30-33
Melons	40	13-20	5- 8
Bananas	26	25-40	7-26
Citrus	43	20-50	9-22
Grapes	25	25-50	6-13
Other Fruits	47	40-50	19-24
Olives	7	50-67	4-5

Item	Lower Middle Income (M.I)		
	Food Consumption (*kg/capita*)	Water Requirement (*m^3/100 kg*)	Water Demand (*m^3/ capita*)
Vegetable Oil	15	500-800	75-120
Miscellaneous[a]			15-20
Red Meat[b]	10	875-1750	88-175
Poultry Meat	22	188-375	41-83
Fish[c]	2	75-150	2-3
Milk[d]	120	69-138	83-166
Eggs[e]	5	300-600	15-30
Total	716		614-1017
Average			815
Agricultural Water $Irr_0 = 815 \times f_0 \times M_i$ (including post harvest losses)			

The irrigated agricultural output/ yield from a unit flow of water is not the same for the countries of the four income categories. Some major factors that cause variation of the yield per unit flow are a) the application of modern technology in farming, b) the amount of capital invested in the farming industry, c) the level of human resources skills in the trade, and, d) the intensity and content of the research and extension programs. The output of a certain crop per 1000 cubic meters of water in a country with advanced agricultural technology like, say, Holland, is multiple times the output of an equivalent water quantity in a country like, say, Pakistan. The reason lies in the advanced farming methods employed in advanced countries like using advanced irrigation systems, protected agriculture, improved seeds, techniques in application of fertilizers, pesticides, and harvesting methods, and the capital invested in agricultural production. The skills of Dutch farmers in such methods are also superior to the skills of farmers in practically all developing countries. Other social and economic factors have their impact on agricultural production. The impact of each of the above factors is difficult to quantify, but can be refined for certain countries where data are available. The level of technological application is more or less proportional to the status of social, political and economic maturity of the country under consideration. The per capita income is undoubtedly one, but not the only factor in determining the ability to apply, maintain and sustain advanced levels of technological applications.

For purposes of this study, an average comparative factor is given to countries of the above categories of economy. A factor (F) is assigned to each income category to indicate the comparative productivity from a unit flow of water applied at the location of the plant (does not include conveyance and distribution efficiency). This factor reflects the comparative advantage of advanced countries over developing countries in connection with the agricultural yield per unit flow of water. The values assigned to the factor, F, are based on experience and observations made in countries of the different income categories. If a value of 1.00 is assigned to countries of Lower Middle Income Economy, a value of 0.75 is a more likely factor for countries of Low Income Economy, 1.50 for Upper Middle Income, and 3.00 is assigned to countries of High Income Economies. This means that a country belonging to the High Income Economy produces, on the average, 200% of the yield attained by a country of the Upper Middle Income, 300% the yield of a Lower Middle Income, and 400% of the yield of a Low Income economy country. The selection of values for the factor F is undoubtedly subjective at this stage, but can be refined with data availability.

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[a] *Includes such items as tea and coffee.*
[b] *composed of beef, sheep and goats. The water requirements, however, are for beef.*
[c] *Assuming fish from fish ponds*
[d] *This is the fluid milk equivalent of both fluid milk and dairy products consumption*
[e] *Egg consumption usually is given in number of eggs rather than in weight; 15 eggs are assumed to weigh 1 kg.*

Another difference between the countries of the different income categories is in the diet itself, with the High Income diets tending to be richer in animal products than the diet of the Middle and Low Incomes. For this difference, a factor f_0 is introduced. Its value is assumed proportional to the income, being higher for higher income.

The water quantities shown in Table 2 include post harvest losses but do not include food processing, storage, overuse, waste and spoil losses. These other losses are accounted for by the introduction of another efficiency factor, f_1, which would be inversely proportional to the income, higher for low income. The inverse relationship indicates that poorer people manage food more carefully and leave less food to waste.

The total water amount needed to grow the food per capita is the quantity measured at the water source. It is equal to the amount applied at the point of use plus the water lost in transit between the source and the point of use. This loss is usually expressed by the irrigation efficiency, E_2. Thus the irrigation requirement, Irr_1, is calculated by:

$$Irr_0 = 815 \text{ x } (f_0/f_1) / E_2 \qquad (2)$$

Or

$$Irr_0 = M_i \text{ x } 815$$

Where,

$$M_i = f_0 /(f_1 \text{ x } E_2)$$

Irrigation efficiency, defined as the ratio between the water that reaches the point of use and the amount of that same water at the source varies from one country to another and from one project to another. In arid and semi arid countries, care is taken to avoid the loss of water because of scarcity. The precaution is normally done through the lining of surface canals of the distribution networks, and the application of land leveling, or through the use of pressure pipe networks. Where projects have extensive irrigation networks, irrigation efficiency is usually lower than that of a farm depending on groundwater and is privately operated. Surface canals networks have lower conveyance efficiency than pressure pipe networks. Likewise, a farm employing drip irrigation methods normally achieves higher efficiencies than farms relying on surface irrigation methods. The more advanced these conveyance systems are the more expensive they are to install, and the better efficiency is achieved. In Jordan, for example, where the irrigation infrastructure in the Jordan Valley is primarily composed of pressure pipe networks, and on-farm irrigation systems are advanced systems (drip, micro-sprinkler), the irrigation efficiency reached an average of 72%, with better efficiency attained during the summer months. Private projects on the Jordanian Plateau depending on groundwater and employing advanced irrigation systems attained higher efficiency. Irrigation projects with surface canals networks, some being earth canals without lining do exist in the Middle East region and the irrigation efficiency is as low as 40% or less. The investment in improving the irrigation infrastructure to attain higher efficiencies depends on the availability of capital and the attention paid by the decision makers to proper water management. Finally, the system of water charges impacts water use efficiency with higher efficiency achieved as the water charges approach at least the operation and maintenance cost. Lower efficiencies prevail where subsidies are accorded to water charges.

Table 3 shows the above factors in comparative form in the Low, Lower Middle, Upper Middle and High Income categories respectively.

Table 3. Efficiency factors, and irrigation requirement (m^3/capita/year).

Income Category	Consumption Factor, f_0	Management Factor, f_1	Conveyance Efficiency E_2	Multiplier M_i	Irrigation Requirement, Irr_0=815x M_i
Low	0.90	0.95	0.54	1.742	1419
Lower Middle	1.00	0.92	0.60	1.811	1476
Upper Middle	1.10	0.90	0.70	1.587	1293
High	1.20	0.85	0.75	1.882	1534

Table 4. Annual irrigation needs (m^3/capita).

Income Category	Irr_0	F	Irrigation Requirement, Irr_1
Low	1419	0.75	1892
Lower Middle	1476	1.00	1476
Upper Middle	1293	1.50	862
High	1534	3.00	511

The productivity factor, F, is now considered to evaluate the irrigation requirement, Irr, of the different categories of income, shown in Table 4.

$$Irr = Irr_0 / F \quad (3)$$

The total water requirement to produce food under total irrigation and to account for the municipal, recreational and industrial needs would be the sum of the needs shown in Table 5.

Table 5. Total water requirement (m^3/capita/year).

Income Category	M&I Requirement	Irrigation Req.	Total Requirement	Approximate Value
Low	123	1892	2015	**2000**
Lower Middle	128	1476	1604	**1600**
Upper Middle	133	862	995	**1000**
High	141	511	652	**650**

Like the case is with municipal and industrial water, the water requirements for food production are not claimed to be exact, but they are a reasonable estimate. It is not unusual to find the productivity per cubic meter of water different from the above. A 20% variation up from the Low and Middle Income productivity figures and 20% lower from the High Income figure can easily be encountered in the field so that the irrigation water requirement per capita could be as high as 2270, 1770, and 1035 cubic meter per capita for the Low Income, Lower Middle Income, and Upper Middle Income respectively, and as low as 408 cubic meters for the High Income countries. In Jordan, for example, the introduction of improved varieties and the use of plastic tunnels in protected farming raised the productivity from 1 ton of tomatoes per 1000 cubic meters of water to three times as much for the same amount of water. Much higher yields have been recorded in cases where drip irrigation and plastic houses were used, and yet higher yields for farms with computer controlled methods of irrigation. The spread of such technologies depends on the farm income, availability of capital, farmers' training and on the activities of research and extension.

Other experts assigned different figures to the productivity of water. Postel cited a productivity of water that renders the per capita requirement for food at 400 cubic meters per year (Postel, 1996). Allan (1994) suggested that a figure of 1000 cubic meter per capita per year is a likely, very conservative figure. A third figure of 1570 cubic meters per capita reportedly has been suggested by the Food and Agriculture Organization (Falkenmark, 1996). Postel's figure could very well apply to advanced countries of High Income Economies, especially where agricultural productivity is of high importance to enhance exports, and Allan's figures could very well be applicable to arid countries of the Middle East of the Upper Middle Income category (Gulf States). His qualification of the figure being highly conservative lies in the fact that some of the arid and semi arid countries fall in the Low Income category where water productivity is less. FAO’s figure compares very well with the figure for the Lower Middle Income category computed above.

Role of rain-fed agriculture

Food is produced through rain-fed farming where irrigation is not needed. In the Middle East and North Africa region, for example, food cannot be produced without irrigation with the exception of the Fertile Crescent, the southwestern corner of the Arabian Peninsula, and the western territories of North Africa. As such, and in countries where rain-fed agriculture is marginal or non-existent, the per capita need of water would be as shown above for the countries of the four categories of income. In countries where rain-fed farming contributes to food production, these figures should be reduced in as much as rain-fed agriculture contributes to food production.

To compute the contribution of rainfall to plant production, we begin by saying that, under conditions prevailing in the rain fed regions, and without ignoring the importance of local climates on effective precipitation, rainfall of intensities of 350-400 mm and more is capable of supporting crops. However, the productivity per unit area of rain fed land, or from a given amount of precipitation over rain-fed areas, does not match the parallel productivity from irrigated agriculture. The reason being the control of timing of water application and the intensive farming techniques of the secure irrigated agriculture as compared to the less secure rain-fed agriculture. Fluctuation of rainfall annually and inter-annually further accounts for less cropping intensity in rain-fed areas and also less productivity than the case is in irrigated agriculture.

From field experience in Jordan, the wheat yield of an irrigated hectare in the irrigated Jordan Valley amounted to 4.5 tons per hectare for certain varieties of wheat, and it averaged about 1.5 tons per hectare in rain-fed areas in the Jordanian Plateau. Yield of other crops (vegetables) under rain-fed conditions show different ratios as percentage of irrigated yields. Worldwide, Peter Gleick (2000) states that the irrigated area was 18% of the crop area in 1998 and produced 40% of the world food. If the balance of food production is attributed to rain-fed agriculture, it means that the productivity of irrigated agriculture is 3.03 times the productivity of rain-fed areas. The calculation is easily made as follows:

$$0.18 \text{ x } A \text{ x } p_i + 0.82 \text{ x } A \text{ x } p_r = Y \quad (4)$$

$$0.18 \text{ x } A \text{ x } p_i = 0.4 Y \quad (5)$$

Where,

A is the total cropped area,
p_i is the productivity of irrigated areas,
p_r is the productivity of the rain-fed areas,
Y is the amount of food produced in the world.

$0.18 \text{ x } A \text{ x } p_i \text{ x } 0.82 \text{ x } A \text{ x } p_r = 0.45 \text{ x } A \text{ x } p_i$
$0.82 \text{ x } A \text{ x } p_r = 0.27 \text{ x } A \text{ x } p_i$
$p_i / p_r = 3.037$ taken at *3.00*

This shows that, worldwide, the productivity of irrigated agriculture per unit land area was three times the productivity of rain fed agriculture. The figure ties in with the data gathered in Jordan.

The cropping intensity is assumed at 80%. This means that 20% of the land that can be cropped under rain fed conditions is left fallow in a given season. The water needed to support a crop in irrigated agriculture is more than the rain needed to support the same crop in rain-fed areas. This is because of the aridity of irrigated areas and the higher evaporation rates therein, and because of the water conveyance losses. In effect, it takes about 750-800 mm of irrigation water to support the irrigated wheat crop as opposed to 350 -400 mm of adequately spaced rainfall to support the rain-fed wheat crop. It does not take any additional water to support a summer crop of vegetables in rain-fed areas, but it takes about 800 mm of irrigation water to produce that crop in irrigated areas, naturally at higher yields. Since the area allocated to winter crops in rain-fed areas is substantially larger than the area allocated to summer crops, it may be assumed that the water needed in irrigating the same crops that rain-fed agriculture supports (winter and summer) is about *twice* as much.

The area of rain-fed agriculture in a given country, assumed to be 1/3 as productive as the irrigated areas, is considered effectively utilizing 350 mm of rainfall (0.35 meters). The volume of water, per capita, thus utilized is calculated by multiplying the rain-fed area per capita times the effective rainfall. Any rainfall in excess of that effective depth goes to runoff and to ground water recharge, both forming the renewable indigenous water resources of the subject country.

An additional allowance of 7% in productivity is added on account of contributions from early morning dew, especially the dew occurring in April and early May. The irrigation water equivalent thus becomes 350 x 1.07 x 2 x 1/3= 250 mm/ dunum/ year, or, approximately 250 m^3/dunum/year (a dunum is 1000 square meters.)

The contribution of soil moisture, due to rain and dew, is expressed by:

$$R_A = 250 \text{ x } R \quad (6)$$

Where,

R_A: is the amount of rain water considered equivalent to irrigation water, in m^3/capita/year,
R : is the per capita share of rain-fed areas, in dunum.

This irrigation water equivalent composed of soil water and dew is added to the water resources per capita to yield the total availability of indigenous water resources.

Example of computation (Jordan as a case)

Given

Jordan's renewable indigenous fresh water resources are reported at 750 MCM. The usable treated wastewater was 55 MCM in the year 2001. The average per capita M&I water served in the municipal networks was 54 cubic meters, and the average non-renewable freshwater over- pumped was 200 MCM as over abstraction from renewable aquifers and 50 MCM from fossil water at Qa' Disi. The average cropped rain-fed area that year was 2 Million dunums out of some 4 Million arable dunums, and the population was 5.2 Million people.

Questions

1. If the country maintained the average diet that is shown in Table 2 above for Lower Middle Income Economy, what was the net exogenous (virtual) water imported through food that year?
2. And if the net deficit in foreign trade in food commodities was 550 Million U.S dollars, what would the water cost to Jordan have been if the imported food were to be grown domestically under irrigated conditions?
3. Had the year 2001 been a good rainy year allowing the cultivation of the entire rain-fed areas, what would the exogenous water be then?

Computation for Answers

The soil water and the dew contribution = $2x10^6/(5.2x10^6)$
= 0.3846 dunum/capita
The indigenous water resources used = 750+250+54+ 0.3846x250
= 1000+54+96
Indigenous water resources = 1150 MCM
Indigenous water used per capita = 1150/5.2 = 221 cubic meters.
Water allocated to agriculture = Indigenous availability – M&I allocation
= 221- 55
= 166 cubic meters
Agricultural water needs per capita:
diet shown in Table 2 above = 1476 m^3/ capita
Indigenous water = 166 m^3/capita
Hence, exogenous (virtual) water, representing the deficit in agricultural water is
= 1476-166
= 1310 m^3/capita

The cost of irrigation water in the Jordan Valley is about \$0.15 per cubic meters (JVA, 1998), hence, the cost to Jordan of water alone would have been \$196 for the entire indigenous water had the food been grown domestically. If water cost were only 10% of the cost of production, then the total cost of the food deficit would have been \$1960, as compared to the \$550 paid for the imported food.

The above analysis suggests that it is much cheaper for Jordan to import food than to grow it under irrigated conditions; but such a straightforward conclusion could be misleading because the other economic and social benefits from agriculture are not accounted for in the comparison of the cost of indigenous and exogenous waters.

The above also suggests that Jordan was able to account for (166/1476) or 11.2% of its food consumption through domestic production, and 88.8% of its food consumption was imported. Moreover, its allocation for M&I purposes was only (56/123) or 45.5% of the actual need. It also shows that, provided foreign exchange reserves are kept adequate, importing food is financially cheaper than producing it domestically. This suggestion does not account for the other benefits that accrue to the country from agriculture, primarily the social benefits, environmental benefits and political benefits.

In good rainy years, Jordan can double the contribution of soil moisture to 192 cubic meters per capita, but it has to reduce dependency on over-abstraction from ground water renewable aquifers by an amount of about 38 cubic meters per capita, rendering the increase in good years to 154 cubic meters per capita, or the availability to 375 cubic meters per capita. If the same allocation is kept to M&I water (because of capacities of transmission mains), the indigenous irrigation allocation would be 320 cubic meters per capita. The domestic production would thus cover 320/1476 or 21.6%. The virtual water would be reduced to (1476-320) = 1156 cubic meters per capita covering 78.4% of the food consumption.

Measurement of water stress and strain

Question 1

Using the data of the above example, compute:

a) the **water stress**
b) the water strain.

Computation

a) Water Stress = Population/ indigenous water resources
= $5.2\text{x}10^6$/ (1150)
= 4521 people/ unit flow of one MCM
b) Water Strain = Water budget deficit/ water needs
= (221- 1600)/ 1600
= **-** 0.86 (shortage)

Question 2

What would the water stress and strain in Jordan be if Jordan were to use only indigenous renewable water resources?

Computation

Indigenous renewable water resources amount to (750 MCM of freshwater and 54 MCM of treated wastewater in 2001 plus 96 MCM soil water), or 900 MCM

a) Water stress = $5.2 \text{ x } 10^6$/ 900
= 5777 people per unit flow
b) Water strain = (900/5.2) – 1600 / 1600
=173-1600/1600
= 1427/1600
= -0.89

Question 3

What would the stress and strain be if 2001 were a good rainy year?

Computation

The good rainy year doubles the soil moisture and its use. The water resources would be 996 MCM (eliminating over pumping and the use of fossil water in agriculture).

a) Water Stress = $5.2 \text{ x } 10^6$/ 996
= 5220 people per unit flow
b) Water strain = (996/5.2) – 1600/ 1600
= 192 – 1600/ 1600
= 1408/1600
= -0.88

Advantages of exogenous (virtual) water

The above analyses display the advantages that exogenous water has in providing a workable way to close deficits in the water budgets of water short countries, especially those of arid and semi arid regions. In absence of such mechanism, competition over water and arable rain fed lands would intensify and could lead to internal disorder and pose threats to regional security.

Despite the fact that indigenous water utilization has numerous advantages over exogenous water whose advantages from exploitation accrue to the countries of source and origin of food commodities, the latter has the definite security advantage and would be favored by politicians who would otherwise have to face impossible choices to bridge the deficit in water budgets.

In addition to its regional and domestic security benefits, exogenous water has a financial advantage over the exploitation of indigenous water resources. However, the chain of economic and social benefits that irrigated agriculture brings about could well outweigh the financial edge that exogenous water brings about.

By the mere fact that water budgets in remote countries can be augmented with water resources from water surplus countries through trade in food commodities, exogenous water opens a venue for globalization of water resources. Other advantages / disadvantages of globalization could very well apply to water resources in the different parts of the world.

Conclusion

The paper presented a method to measure exogenous (virtual) water which is embedded in the imports of food commodities. It shows that exogenous water accounts for a substantial portion of the water available to countries in the arid and semi arid countries, taking Jordan as an example.

The availability of exogenous water had been a conduit to the globalization of water resources. Through food imports, a consumer in Tunisia, for example, can share with the consumer in the American Midwest the benefits of the rain fed wheat belt there. The same can be said about other water short countries whose water budget deficit can only be bridged through exogenous (virtual) water. This fact opens an avenue for globalization of water resources with all the advantages/disadvantages such globalization may bring about.

Without exogenous water availability, water short countries can be in deep trouble trying to secure food samples to their populations. That would be a troublesome burden on the shoulders of politicians and would cast a shadow of perpetual conflict that could deteriorate regional security.

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The concept of ‘virtual water’ and its applicability in Lebanon

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Abstract

‘Virtual water’ is a recently emerging strategy concept, developed as a prospective long-term solution for increasing stress on water resources worldwide. It suggests that water poor countries import agricultural products requiring a large amount of water for their production from other areas that are more endowed with water. This paper introduces the concept of ‘virtual water’, its role in managing water resources and its social, economic, and political implications. It then examines its potential applicability in the context of Lebanon, after describing the country’s water sector. The analysis suggests that, theoretically, the country is a potential virtual water exporter to neighboring arid and semi-arid countries. However, Lebanon is importing significant volumes of virtual water (171-260 m^3/capita/year) in agricultural crops, and yet is threatened to face water shortage in the near future. As such, it is recommended that Lebanon should first manage the water sector locally through proper policy setting prior to exploring its potential role in virtual water trade.

Introduction

Demand for the world’s increasingly scarce water supply is rising rapidly with the growing world population. In 1995, the world water withdrawal amounted to $3{,}906 \times 10^6$ m^3. By 2025, water withdrawal for most uses is projected to increase by at least 50 percent (Rosegrant *et al.*, 2002a). As such, water scarcity is considered one of the most pressing issues of the 21st century, particularly in arid regions of the world, where it has developed into a major threat to food security, human health and natural ecosystems. In fact, it is estimated that currently, nearly 1.4 billion people (or the equivalent to a quarter of the world’s population or a third of the population in developing countries) live in regions that will experience severe water scarcity within the first quarter of the next century (Seckler *et al.* 1999). Out of these 1.4 billion, more than 1 billion people live in arid regions that will face absolute water scarcity by 2025. These regions do not have sufficient water resources to maintain 1990s levels of per capita food production from irrigated agriculture and to meet reasonable water needs for domestic, industrial and environmental purposes. The remaining 348 million people face severe economic water scarcity, where the existing water resources are sufficient to meet reasonable water needs by 2025, but require development at significant costs and possibly severe environmental damage (Seckler *et al.*, 1999). Irrigated agriculture, accounting for about 80 percent of global water consumption and 86 percent of 1995 water consumption in developing countries, is the primary sector to be affected by water shortage. There is a major threat that the water available may be inadequate to meet growing food demands (Rosegrant *et al.*, 2002a), particularly in water-short countries.

Growing water scarcities in much of the world pose severe challenges for national governments and international development and environmental communities. The challenges of growing water scarcity are augmented by depletion of groundwater, water pollution, degradation of water-related ecosystems, soil deterioration in irrigated areas, and the increasing costs of developing new water and wasteful use of already developed water supplies, encouraged by subsidies and distorted incentives that influence water use. As such, there is a pressing need for governments and the international community to manage the world’s water resources efficiently and adopt policy reforms at the national, regional, and international scale. A recently emerging strategy concept developed as a prospective long-term solution for preserving water resources that is the subject of much interest/debate nowadays is known as ‘virtual water’. This concept suggests that water poor countries import commodities, mainly agricultural products, requiring a large amount of water for their production from other areas that have more water. This paper introduces the concept of ‘virtual water’ and its role in managing water resources and its social, economic, and political implications. It then examines its potential applicability in the context of Lebanon, after describing the country’s water sector.

Virtual water

Virtual water is the volume of water needed to produce a commodity or service (Allan, 1997). For instance, it takes approximately 2,000 tons of water to produce one ton of rice, 1,000 tons of water to grow one ton of wheat, and approximately 1,200 tons of water to produce one ton of maize (Allan, 1997; Turton *et al.*, 2000). As countries trade in agricultural commodities, they are actually also importing and exporting water in a virtual sense. Vast quantities of virtual water are embedded in the international political economy, with almost every state being subjected to trade in virtual water (Meissner, 2002; Allan, 1997). For instance, at the end of 2001, South Africa exported about 9,000 tons of maize to Zimbabwe. In a virtual water sense, South Africa has exported 10.8 million tons of water (Turton *et al.*, 2000). In the Middle East, the amount of water that enters the region as virtual water in the form of subsidized grain purchases is equivalent to the annual flow down the Nile (Allan, 1997). Many countries currently compensate for their poor water endowment by food imports. The southern Mediterranean countries are a typical example, though they practice virtual water trade implicitly, avoiding this issue in public discourse due to the political sensitivity of food self-sufficiency (Yang & Zehnder, 2002). Table 3 provides estimates of volumes of virtual water embedded in food imports into selected countries, presented as annual averages for 1995 to 1999.

Table 1. Net food imports and virtual water equivalent (Yang & Zehnder, 2002).

	Algeria	*Egypt*	*Israel*	*Libya*	*Morocco*	*Tunisia*
Average annual virtual water embedded in domestic cereal production, 1995-1999 (m^3 / capita)	94	236	34	38	212	169
Average annual virtual water embedded in net cereal imports, 1995-1999 (m^3 / capita)	192	140	453	390	124	202
Average annual virtual water embedded in net non-cereal agricultural food imports, 1995-1999 (m^3 / capita)	101	85	334	152	76	50
Average annual virtual water embedded in meat, animal fat and milk imports, 1995-1999 (m^3 / capita)	42	15	53	24	7	5
Sum of the virtual water imports (m^3 / capita)	335	240	840	566	207	257
Ratio of virtual water imports to renewable water resources	0.71	0.27	2.72	5.66	0.19	0.59

In this context, the concept of 'virtual water' lends itself as a potential solution to water scarcity in semi-arid and arid regions, which can achieve both water and food security by purchasing water intensive agricultural commodities from water-rich states that produce a natural surplus of these products. Such a strategy is particularly relevant in years when the world prices of food grains are lower than the cost of production in water short nations. Because trade of real water between water-rich and water-poor regions is generally impossible due to the large distances and associated costs, it is increasingly recognized that virtual water trade might be the means by which water-deficit economies balance their water budgets (Turton, 1998). Concurrently, food trade can contribute to national food security by 1) augmenting domestic supply, 2) reducing supply variability but not necessarily price instability, 3) fostering economic growth, 4) making more efficient use of world resources (water and soil in particular), and 5) permitting global production to take place in those regions most suited to it (Konandreas, 1996, cited in Turton *et al.*, 2000). As such, virtual water and the trade therein can be a very realistic policy measure for countries situated in arid to semi-arid regions. It can be seen as a demand-side management strategy to supplement water resources where they are scarce, thus achieving water security in water-poor regions of the world and enabling national water and food needs to be met. Yet, the implementation of a viable virtual water strategy is more complex, being influenced by a multitude of factors at both the national and international scale (Meissner, 2002).

Implementing a viable virtual water strategy

While virtual water appears appealing to water-short nations to achieve food and water security, the adoption of a national virtual water strategy should be consistent with national objectives other than food security including, providing national security, promoting economic growth, and improving the quality of life for citizens (Wichelns, 2001). In this context, besides water, resources required for agricultural production such as land, labor and capital, need to be considered when evaluating a nation's production and trade opportunities. In countries where one or more of these resources is limiting, focus on virtual water alone will not be sufficient to determine optimal policies for maximizing the social net benefits from limited water resources. For instance, in a country where labor is relatively abundant, policies that promote increased export of labor-intensive crops will improve rural income and enhance food security. Hence, a country should encourage the production of labor-intensive crops while promoting water conserving irrigation practices (Wichelns, 2001). Another factor that needs to be evaluated is the opportunity cost of water used in producing crops, which is its value in other uses such as the production of alternative crops, or its use in municipal, industrial, or recreational activities. Accounting for opportunity costs is essential for estimating the benefits from importing or exporting virtual water. It also allows an efficient allocation of scarce water resources at the national level. For instance, countries in which water is particularly scarce may gain from trade by importing water-intensive crops, while using their limited water supply for activities that generate greater incremental values (Wichelns, 2001).

Turton (2000) identifies four key hydropolitical variables that determine the potential for a nation to be involved in virtual water trade including, water need, economic strength, and agricultural and industrial sectoral water efficiencies (SWE). According to Turton, of all the possible combination of variables, economic strength is the most important. For a country to be able to purchase virtual water, it should have an economy capable of generating sufficient foreign currency reserves. Only countries with a healthy balance of payment situation are in a position to trade in virtual water as needed to balance their water budgets. This can come from the existence of a viable industrial sector that is globally competitive (Turton, 2000). As for the SWE, or the ratio of water consumed within a given economic sector in relation to contribution of the same economic sector to overall Gross Domestic Product (GDP), it reflects the degree of efficiency of water use to a political economy. Typically, agriculture uses the largest portion of water in a given political economy, and only contributes a small component to the GDP of a country. Industry, on the other hand, uses less water and contributes a significantly larger fraction of the overall GDP. Thus, in general terms, the agricultural SWE is low whereas the industrial SWE tends to be high. Hence, in water scarce countries, it is advisable that water be diverted away from agricultural use into the industrial and urban domestic sectors, whereby 70 times more economic value can be achieved for a given volume of water (Turton, 2000). Table 1 illustrates various combinations of the hydropolitical variables determining the potential role of countries in a virtual trade strategy.

Table 2. Hydopolitical variables and the potential of nations in virtual trade.

IF				***THEN***
Water need	*Economic strength*	*Agricultural SWE*	*Industrial SWE*	
High	Weak and undeveloped	Low Focus on subsistence agriculture	Low	No potential for a VW strategy
Low Medium	Weak and undeveloped	Low with potential for improvement The presence of arable land The presence of a favorable water resource base	High	Potential VW export
Low	Strong & diversified	High	High	
High	Strong & diversified	Low	High	Potential VW import
High	Strong & diversified	Medium	Medium	
Medium	Strong & diversified	Low	High	

Other factors that ensure a viable virtual water strategy, include:

- A sound national trade policy that is in harmony with regional trade policies, facilitating exchange of goods (Turton *et al.*, 2000)
- Cooperation between states
- The establishment of an international organization to control global food trade and ensure that the global distribution of food will not be used as a political weapon (Bouwer, 2000)

Virtual water value of food crops

Virtual water calculations are an essential planning tool for determining how water can be used most efficiently to attain both food and economic security (Meissner, 2002). This is achieved by developing a virtual water trade balance that includes net import versus net export of virtual water for each crop. The virtual water value per crop is estimated by multiplying the volume of water required for the production of a given biomass of this crop, referred to as the virtual water value, by the total amount of crops produced (Turton *et al.*, 2000). However, the virtual water value of crops is dependent on many factors, including the geographic location of the region where the crop is grown, the irrigation system used, the management of the irrigation system, the soil type, climatic conditions, etc. In other words the virtual water value of an agricultural commodity is only a rough estimation and is site-specific.

Advantages and limitations

Virtual water trade presents itself as an alternative source of water to governments confronted with water scarcity, having an added advantage of being environmentally sound, relieving stress on the indigenous scarce water resources. Furthermore, nations involved in virtual water trade are interdependent on each other with respect to their food trade and food security. Hence, virtual water can be viewed as a diplomatic and economic tool for attenuating conflict potential between nations and creating new enduring modes of international communication (Turton *et al*., 2000).

On the other hand, at present, access to global markets is not fair and the playing field is far from being leveled. This has major implications for a virtual water development strategy (Turton *et al.*, 2000). Furthermore, economically sound water pricing is poorly developed in many regions of the world, whereby many products are put on the world market at a price that does not reflect properly the cost of the water contained in the product. This leads to situations in which water-poor regions subsidize the export of water. Finally, the reliance on trade can hold some risks, including the hazards of deteriorating terms of exchange on world markets, uncertainty of supplies, world market price instability and increasing environmental stress if appropriate policies are not in place (Konandreas, 1996 in Turton *et al*., 2000). This could be alleviated by combining food imports with domestic production and storage strategies to respond more easily to unexpected changes rather than relying solely on imports.

The case of Lebanon

The countries of the Middle East are characterized by large temporal and spatial variations in precipitation and by limited surface and ground water resources. Rapid growth and development in the region have led to mounting pressures on scarce resources to satisfy water demands. The dwindling availability of water to meet development needs has become a significant regional issue, especially as a number of countries are facing serious water deficit. It is estimated that 9 out of 14 Middle Eastern countries have a freshwater potential of less than 1,000 m^3/person/year, resulting in a concentrated region of water scarcity. In Lebanon, the use of water resources is approaching unsustainable levels because of increased consumption associated with population growth, industrial development, expansion of irrigated agricultural land and escalating uncontrolled exploitation of groundwater resources. The general physical characteristics of the country are summarized in Table 1.

Table 3. Summary of Lebanon’s physical characteristics (adapted from El-Fadel et al., 2002)

Background	*Description*
Climate	• The location along the shores of the Eastern Mediterranean Sea results in a temperate climate. • Conditions are not uniform throughout the country and are affected by the presence of two mountain chains: the “Mount Lebanon” and the “Anti Lebanon” mountains, both of which run in a predominantly north-south direction. • The winters are short and relatively dry, while sunny conditions dominate the rest of the year. • The prevailing winds are westerly coming from above the sea and carrying elevated humidity. • The average humidity is about 70 percent along the coast and decreases with inland progression. • The annual precipitation varies from a low of 200 mm/year in the northern inland extremes of the Bekaa Plateau to more than 1,500 mm/year at the peaks of Mount Lebanon with an average of about 843 mm/year over the whole country (Figure 1).
Geomorphology	• Despite its relatively small area (less than 10,500 km2), Lebanon exhibits contrasting physiological features and well-differentiated geomorphologic regions. The country can be divided into four main regions from West to East (Figure 2): - A relatively flat and narrow coastal strip with an average width of 2 to 3 km running north to south. - The “Mount Lebanon” mountain chain parallel to the coastline with mean elevations of 2,200 m and peaks upwards of 3,000 m. - The Bekaa Plateau, a land depression at an average altitude of 900 m above mean sea level, with a length of 125 km and a width varying from 7 km in the south to nearly 20 km in the north. - The “Anti Lebanon” mountain chain which also runs in a north-south direction lying east of the Bekaa Plateau and reaching elevations of 2,600 m.
Geology	• Formations are mainly composed of fractured karstic limestone, with volcanic formations in the extreme north. • The identifiable geologic formations are composed of different successive deposits that range in age from the early Jurassic (oldest identifiable units) to the most recent Quaternary deposits.
Groundwater	• Two calcareous formations of the Jurassic and Cenomanian age form the two major aquifer systems. • Eocene, Miocene, and Quaternary layer aquifers of local importance exist (Figure 3). • Estimates for the water quantity available for exploitation range from 400 to 1,000 MCM/year.
Surface Water	• Lebanon has 40 streams, 14 to 17 are classified as perennial rivers depending on the source of information, while the remainder are seasonal (Figure 4). • Two rivers cross the international border into neighboring countries and a third river forms the northern border with Syria, while the rest flow westwards from their source in the heights of Mount Lebanon towards the Mediterranean Sea. • There are more than 2,000 seasonal fresh water springs that feed into various streams.
Coastal and submarine springs	• Springs have been identified in Chekka, Tyre, Damour and Awali areas. • The total annual discharge from the permanent springs in Chekka may reach a high of 730 Mm^3 with a low of 300 Mm^3. The discharges of Damour and Awali submarine springs have been estimated at 31 Mm^3. • Located 500 to 1,500 m off the shore at depths varying from 20 to 85 m, rendering the offshore exploitation technically difficult and financially expensive. • Substantial mixing between the freshwater and the seawater occurs, which renders it unfit for use.
Water Storage Features	• Water storage in ponds, lakes, and small dams for domestic and irrigation purposes is prevalent. • Surface water ponds of variable capacity are constructed in proximity to irrigated agricultural areas, while small dams on rivers are mainly used to produce hydroelectric power.

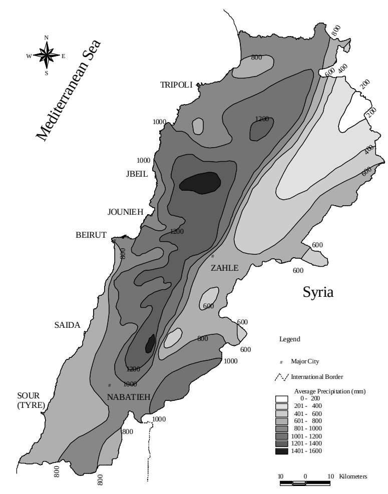

Figure 1.Mean annual precipitation in Lebanon

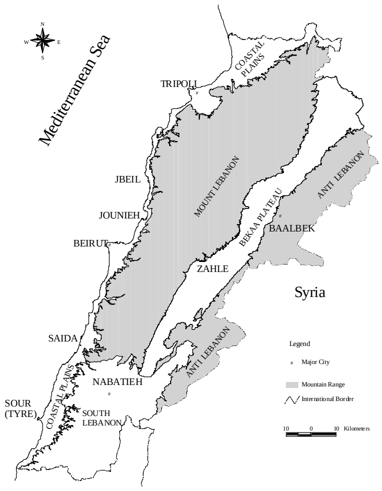

Figure 2. Physiography of Lebanon

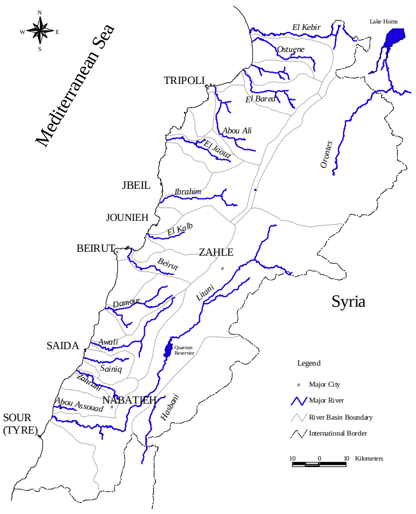

Figure 3. Major river basins in Lebanon

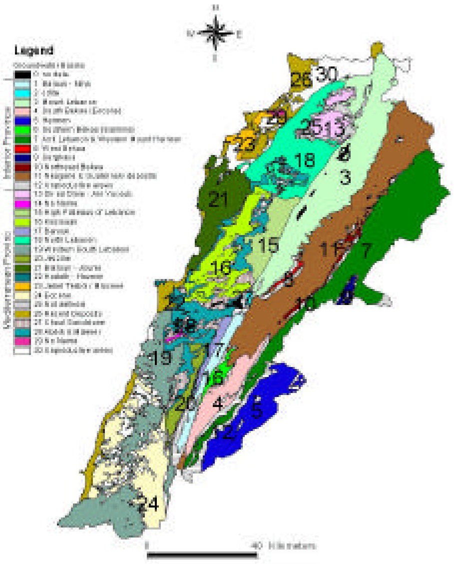

Figure 4. Ground water basins in Lebanon

Water balance in Lebanon

Estimates of the water balance in Lebanon have been reported in several studies making it difficult to derive realistic and representative numbers. Nevertheless, typical estimates on water utility in Lebanon are summarized in Table 2. About 50 percent of the average yearly precipitation of 8,600 MCM is lost through evapo-transpiration. Other losses include surface water flows to neighboring countries (almost 8 percent) and groundwater seepage (12 percent) leaving 2,600 MCM of surface and groundwater that is potentially available, of which 2,000 MCM are exploitable.

Table 4. Annual water balance in Lebanon (El-Fadel et al., 2001).

Description	Yearly Average Flows (MCM)	
Precipitation		8,600
Surface water evapotranspiration losses (assumed to be 50% of precipitation)		- 4,300
Surface water flows to neighboring countries		
El Assi (Orontes) river	- 415	
El-Kebir river	- 95	
Hasbani river	- 160	
Subtotal	*- 670*	- 670
Groundwater flow		
Unexploitable groundwater or losses to the sea	- 880	
Losses to neighboring countries	- 150	
Subtotal	*- 1,030*	- 1,030
Net potential surface and groundwater available		2,600
Net exploitable surface and groundwater		*2,000*

Water demand and supply

Water demand has traditionally been shared between three principal sectors, namely, agriculture, domestic, and industry. Agriculture is by far the largest consumer of water in Lebanon accounting for more than two-thirds of the total water demand (Table 6). This increases the cost of water resource management, and diverts valuable water resources from other potential uses especially the supply of potable water.

The traditional and future water demands vary widely because of different assumptions used in the estimation process, particularly in relation to annual population growth, average per capita consumption, available land for agriculture, average per hectare consumption and future industrialization potential. While the numbers vary, the consensus is that there will be a deficit in the quantities of water required within the next ten to fifteen years as depicted in Figure 5. Using the water balance presented in Table 4, it is clear that the total quantity of fresh water available for exploitation (2,000 MCM/year out of 2,600 MCM/year) will result in a water shortage in the near future; hence the need to address the issue of water management through proper policy setting.

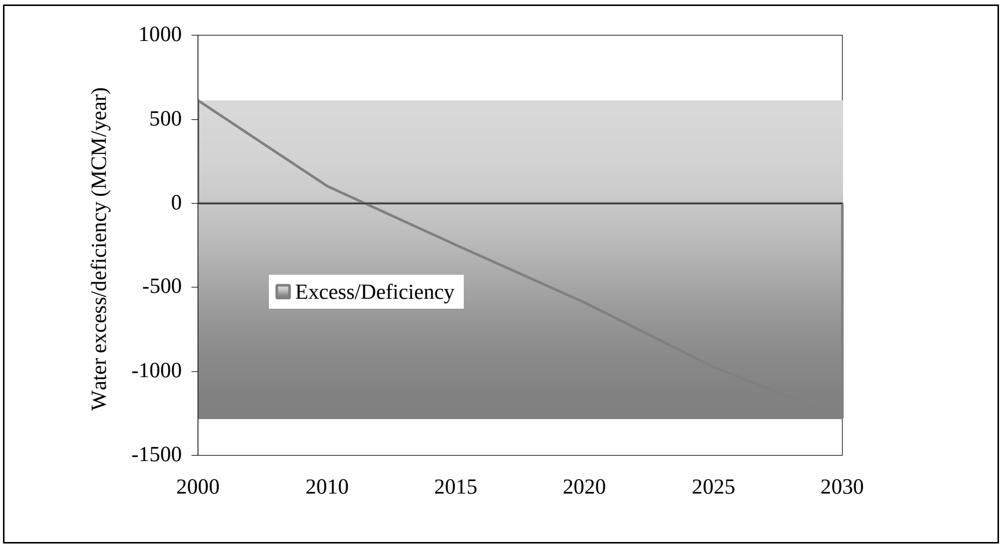

Figure 5. Lebanon's future water demand and deficit

Agricultural water use

As mentioned above, the agricultural sector is the largest consumer of available water resources in Lebanon. The produced crops fall into five major categories: 1) cereals, 2) fruits (not including olives), 3) olives, 4) industrial crops (e.g., sugar beet, tobacco), and 5) vegetables. While the total land area under cultivation has remained fairly constant during the past decades, irrigated lands have more than doubled, from 40,775 hectares in 1961 to 104,009 hectares in 1999 (MoA/FAO, 2000, cited in MOE, 2001). This reflects the intensification of agricultural practices and its associated pressure on the country's water resources. Agricultural production is concentrated in the Bekaa, which accounts for nearly 42 percent of the total cultivated land. The Bekaa hosts 62 percent of the total area used for industrial crops (including sugar beet, tobacco, and vineyards) and 57 percent of the total area used for cereal production (Table 5).

Table 5. Land used for major crop types (MOA/FAO, 2000, cited in MOE, 2001).

Mohafaza	*Cultivated land (ha)*				
	Cereals	*Fruit Trees*	*Olives*	*Industrial crops*	*Vegetables*
Mount Lebanon	314	9,782	7,768	161	3,110
North	12,038	13,568	20,963	3,777	12,858
Bekaa	29774	21,757	3,144	15,323	25,974
South	3764	12,330	8,934	1,462	2,075
Nabatiyeh	5,952	2,077	11,612	4,003	1,214
Total	*51,842*	*59,515*	*52,421*	*24,726*	*45,232*

Irrigation water is provided by both surface and groundwater. Figure 6 reveals that irrigation water is almost equally supplied from surface water and well water (48 and 52 percent, respectively). The number of farms that have private water wells is believed to be increasing rapidly although there are no data on water wells to support this claim. One of the main concerns with the expansion of irrigated agriculture is the high dependence on gravity irrigation. Gravity irrigation accounts for 64 percent of the total irrigated land and is the predominant method of irrigation with surface water. Compared to sprinkler and drip irrigation, gravity irrigation inherently carries high water losses, due to low system efficiencies and high evaporation losses. While efficiency of gravity irrigation could be significantly improved using optimal water and crop management schemes, the majority of farmers in Lebanon lack basic agricultural training.

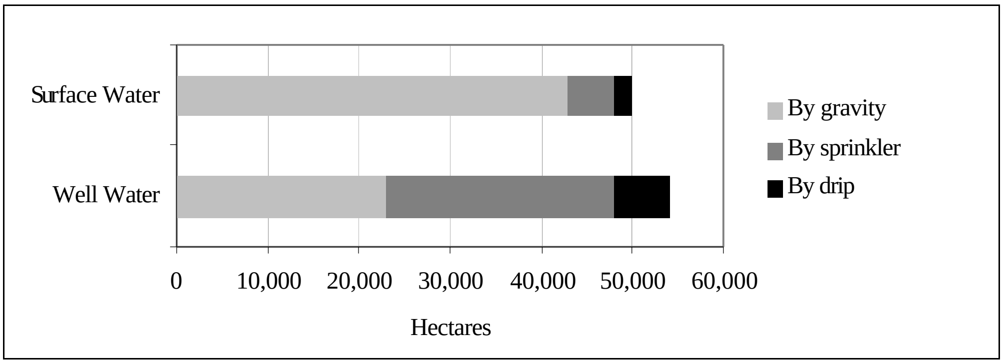

Figure 6. Distribution of irrigated lands by water source and irrigation method (MOA/FAO, 2000, cited in MOE, 2001).

Virtual water trade in Lebanon

The role of Lebanon in virtual water trade is controversial. Compared to the Middle East region, Lebanon is at an advantage in terms of available renewable water resources, and thus is expected to export virtual water to neighboring water-short countries. This is further ascertained by hydro-political variables identified by Turton (2000). According to Table 2, Lebanon falls within the category of potential virtual water exporters, being characterized by:

- Medium water needs
- A weak economy with high internal and external debt that limit its ability to generate sufficient foreign exchange for importing food crops
- A very low agricultural SWE and a high industrial SWE (Table 6)

Table 6. Sectoral water efficiency in Lebanon

Type of Use	*Total water demand* [a]		*Contribution to GDP* [b] *(%)*	*SWE*
	Mm^3/year	Percent		
Agriculture/Irrigation	875	72	4	0.05
Industry	65	6	23	3.83
Domestic/Service	271	22	73	3.32
Total	*1,211*	*100*	*100*	

[a] MOE, 2001 for the year 1990
[b] Beaumont, 2002
[c] SWE = Sectoral Water Efficiency = % contribution to GDP / % water demand by sector

In contrast, an examination of average exports and imports of major agricultural crops in recent years 1997-2001, reveals that Lebanon is practically an importer of agricultural crops where the total annual import is more than twice the export (Table 7). Accordingly, the calculated virtual water embedded in imports, based on water requirements of crops grown in the Middle East and North Africa (MENA) region, exceeds the virtual water export by 8-9 times. As such, the net flow of virtual water embedded in agricultural crops into Lebanon ranges from 171-260 m^3/capita/year. This value exceeds significantly the domestic water usage (99.5 m^3/capita) reported in the 1990s and constitutes 50-80 percent of total water withdrawals (323.5 m^3/capita) (Beaumont, 2002). The major contributor to the flow of virtual water into the country is the import of wheat and rice, having excessively high water requirements as compared to other crops grown domestically.

Table 7. Average annual virtual water trade balance

Item	Water requirement [a] (m^3/ton)	Average annual import [b] (tons)	Average annual export [b] (tons)	Average annual virtual water embedded in imports (MCM [c])	Average annual virtual water embedded in exports (MCM)
Wheat	1,150-1,440	393,674.8	10.6	452.73-566.89	0.01-0.02
Rice	1,080-1,700	45,903.2	1,308.6	49.58-78.04	1.41-2.22
Potatoes	140-220	48,425.4	83,672.8	6.78-10.65	11.71-18.41
Dry pulses	1,670-3,300	39,984.4	1,894.0	66.77-131.95	3.16-6.25
Seeds	2,000-5,000	47,372.8	1,776.6	94.74-236.86	3.55-8.88
Fresh vegetables	200-220	39,488.2	22,061.4	7.90-8.69	4.41-4.85
Melons	130-200	7,592.6	2,060.6	0.99-1.52	0.27-0.41
Bananas	250-400	60.8	3,039.6	0.02-0.02	0.76-1.21
Citrus	200-500	69.8	98,710.0	0.01-0.03	19.74-49.36
Grapes	250-500	624.6	23,475.4	0.16-0.31	5.87-11.74
Other fruits	400-500	4,265.1	56,380.2	1.70-2.13	22.55-28.19
Olives	500-670	17.4	44.0	0.009-0.01	0.02-0.03
Tea, coffee	150-200	23,757.2	1,124.8	3.56-4.75	0.17-0.22
Total		651,236.4	295,558.6	**684.95-1,041.87**	**73.65-131.80**
Total (m^3/capita/year)				**171.2-260.5**	**18.4-32.3**

[a] Measured at the root of the plants for MENA (Middle East and North Africa) countries as reported by Haddadin, 2002
[b] Average value calculated for the years 1997-2001 as reported by the Lebanese Ministry of Agriculture, http://www.agriculture.gov.lb/production99/annee_veg.htm
[c] MCM = million cubic meters

With such significant volumes of virtual water flowing into the country in the form of water-intensive crops, it is expected that a country like Lebanon to have minimal water shortage threats. Yet, the consensus among local experts is that Lebanon will face a water deficit in the near future (Figure 5). This ascertains that current water use practices, particularly by the agricultural sector, are unsustainable and inefficient. In fact, it is quite evident that the water sector in Lebanon is facing several constraints and problems, which need to be addressed through an integrated approach that combines practical technology with political and social support to avoid water shortages in the future (Table 8). Note that the majority of these constraints are also common to countries of similar characteristics. The major difficulties include 1) mounting relative water scarcity, 2) water quality deterioration, 3) inter-sectoral water allocation conflicts, 4) inefficient cost recovery and wasteful operational performance, 5) excessive government involvement and bureaucratic restraint, and 6) weak institutional arrangements. Hence, it is suggested that efforts be directed towards relieving these constraints at the local level, before moving towards the optimization of virtual water trade.

Table 8. Constraints facing the water sector (adapted from El-Fadel et al., 2001).

Category	Constraints
Technical	• Insufficiently skilled staff with few qualified technicians and a lack of up-to-date training, and limited equipment resulting in an inability to conduct proper routine maintenance, measurements or monitor water supply and quality. • Inadequately maintained, relatively old, and often becoming undersized distribution network that leads to water losses in excess of 50 percent. • Poor upkeep and operation of chlorinating equipment at water treatment plants. • Groundwater contamination by bacterial and chemical pollutants. • Illegal removal of flow limiting devices by water users. • Lack of standby pumps and generators to maintain water supply distribution in case of power failure. • Illegal connections to the water supply network. • The usage of severely damaged and outdated irrigation networks leading to excessive water loss and inefficient distribution. • Lack of implementation of modern irrigation and water saving technologies. • Improperly designed water distribution network with bad branching connections to the main system that cannot handle the current and future load generated by increased demand. • Infiltration of wastewater into the water supply leading to contamination.
Financial	• Deficient allocation of funds for proper maintenance and rehabilitation of the water supply and distribution system. • Inadequate collection of fees from consumers leading to poor financial resources for water authorities. Imposed dues and tariffs are insufficient to cover the salaries of employees resulting in limited funds to carry out any additional work on the water network. • The pricing of water has not been properly reviewed and updated for decades.
Administrative and institutional	• Inadequate setup of water authorities that have loosely defined and limited responsibility. • Lack of coordination between water authorities. • Reluctance to cooperate and share data between administrative bodies. • Distribution of water offices and boards is set by geopolitical boundaries rather than water basin limits. • Lack of current verified data about water availability due to faulty meteorological and hydro-geological information. • Non-existent countrywide planning. • Staffing is based on political influence rather than proper technical qualifications. • Legislation that requires reviewing and updating to remove overlapping and multiple responsibilities, and address environmental and health issues. • Ad hoc water quality standards based on international guidelines and not on country-specific or economic risk assessment and sustainable development studies. • Lack of law-enforcement of water regulations regarding use and distribution, particularly in relation to drilling of groundwater wells and payment of fines.

Category	Constraints
Natural	• The majority of the rainfall occurs within a short period of time (about 80 days) during the winter with practically no precipitation during other periods. • The peak demand for irrigation of agricultural lands occurs during the summer (dry season) when water is least available. • The geologic formations of the mountains with fissured karstic bedrock and narrow steep valleys have high erosion potential and make it difficult to efficiently store surface waters behind dams or within impoundments. As such, the majority of surface waters are lost to the sea unutilized.

Conclusion and recommendations

Virtual water, described as the volume of water embodied in food crops, is a recently emerging concept for the management of water resources at the national and international levels. It suggests that water-short countries import water intensive crops from water-rich counties, while using their limited water supply for activities that generate greater incremental value. An examination of the case of Lebanon in virtual water trade revealed that theoretically, the country is a potential virtual water exporter to neighboring arid and semi-arid countries. However, practically, Lebanon is importing significant volumes of virtual water (171-260 m^3/capita per year) in agricultural crops, and yet is threatened to face water shortage in the near future due to local constraints. As such, it is recommended that Lebanon should first manage the water sector locally through proper policy setting. The next step would be the investigation of virtual water trade as a potential management option. However, such a step requires careful consideration of various fundamental issues and national objectives, including issues of national and food security, economic growth, and quality of life of citizens, supported by serious efforts to gather relevant country-specific data, particularly, crop requirements in terms of irrigation, land, labor, and capital and the opportunity cost of agricultural water use.

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13

The virtual water trade amongst countries of the SADC

A. Earle and A. Turton

Abstract

Viewed as a group, the countries of the Southern African Development Community (SADC) are well watered; with almost double the amount of water per capita regionally than the countries of western Europe have available. Yet, the region is characterised by large-scale variations in the temporal and spatial distribution of rainfall and water resources, making averages more or less meaningless. Certain states already experience high levels of water stress with others predicted to be in such a category within the next two decades. Due to the large variation in the level of water resources between countries of the SADC various water transfer schemes have been built or proposed. At present substantially more water flows into the region as virtual water from grain imports than transfers between countries. Just as there are differences between the amounts of water available to each country so too are there differences in the reliance on virtual water amongst states. These differences include not only the degree of reliance on virtual water imports but also the factors causing the reliance. This paper seeks to develop a typology of factors influencing the degree of reliance on virtual water by states generally, as well as analysing the interaction between food security within the SADC and international agricultural trade conditions. The level of virtual water trade between SADC states is very low, and yet it is determined that there are states in the SADC which are well suited to grain production. Additionally there is also a market for this grain in the rich SADC states facing water stress. It is proposed that investing in the grain production and transportation infrastructure of the well-watered, but economically underdeveloped, SADC states by the richer states is more sustainable and viable than building new large water transfer schemes.

Introduction

Agriculture is central to any food security policy as it accounts for all food grown on land. Self evident as this may be, it is important to remember that there is a finite amount of land and, more importantly, water available suited to the production of food. The big question is deciding where and how this food should be produced. In the past, food self-sufficiency, achieved by meeting all food needs through domestic supplies, was a policy objective of many countries. It had the effect of keeping foreign exchange in the country, where it could then be used to import products not locally produced. Yet in the early 1990's, nearly 80 percent of malnourished children lived in developing countries which produced food surpluses (FAO, 2000a). The trend within the SADC is to move toward a policy of national food security, relying on other sectors of the economy to generate capital used to import various food-products not produced locally. The theory of comparative advantage would dictate that countries tend to focus on manufacturing products in which they have a, comparative, advantage in the factors of production.

In the arid regions of the world, water is perceived as the factor of production in short supply. It also happens to be a relatively mobile natural resource, compared to factors such as soil and sunlight. Great water transfer schemes have over the centuries ensured the security of supply for various water-short civilisations. These transfers imply dependence on foreign sources and have political, economic as well as environmental repercussions. Water transfer schemes between countries in the SADC are relatively little used, moving about 5 km^3 of water per year between them (Heyns, 2002). Far greater is the amount of water entering the region as virtual water calculated to be about 8 km^3 per year in 2002, or about 1000 tonnes of water for every tonne of grain (Figure 1). It is this flow of virtual water which contributes significantly to food security in the region. The countries using regular long-term food imports as part of their food security strategy have managed not to rely on food aid during the current food crises in the region.

Certain states in the region – Angola, the DRC, Mozambique and Zambia have the potential to become large-scale surplus grain producers, providing food for the region. That this has not happened has more to do with politics and economics than with geography or climate. Once it is established that the production capacity exists within the region it is necessary to gauge if there is a market willing and able to pay for the product. This is where there are benefits to the rich, water stressed states of the region, which through trading in virtual water can reduce the need for large-scale water transfer schemes. The reasons for the virtual water trade within the region not taking off are explored, with possible opportunities for the future looked at.

Throughout this analysis on the interaction between water, food and trade the focus is on grains. The reason for this is that grains, including wheat, maize, rice, sorghum, millet and barley, comprise roughly 60 percent of the daily calorific intake of SADC countries (FAO, 2002a). The island SADC states (Seychelles & Mauritius) are not included in this analysis.

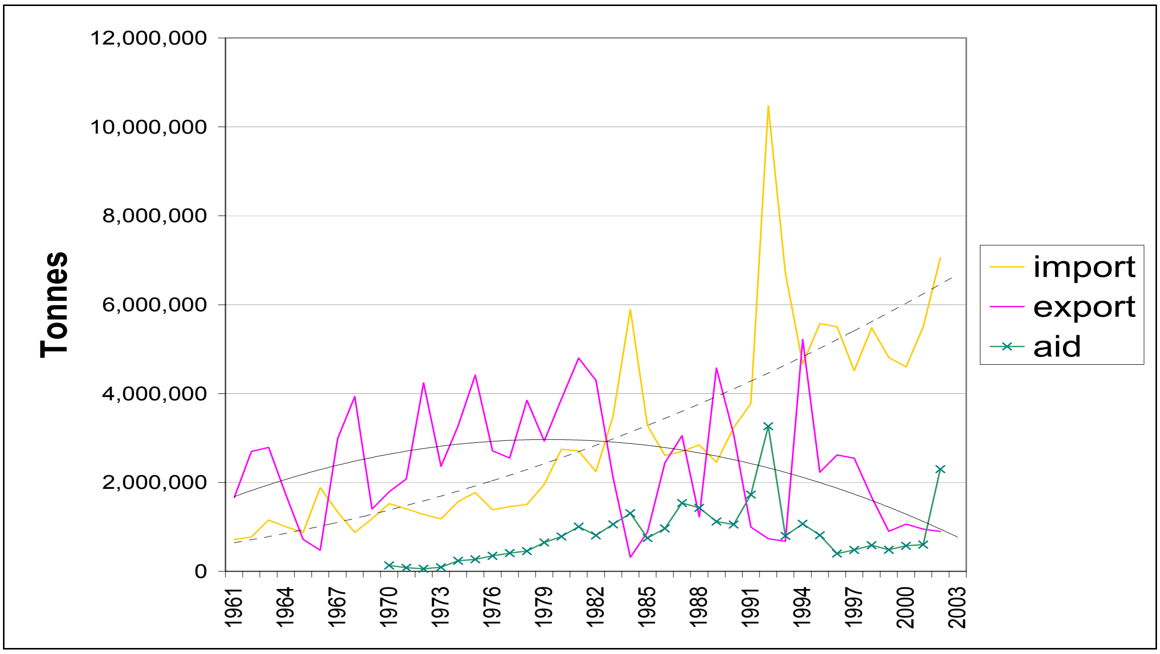


Figure 1. Grain trade & aid in the SADC (FAO, 2002).

Water resource scarcity in the SADC

There is some debate as to what constitutes water scarcity in a country. On a per capita basis Namibia, with 9,967 cubic metres per person annually, has three times more water per person than France does, at 3,439 cubic metres per person annually (FAO Aquastat, 2002). This fact is routinely ignored in water scarcity assessments and highlights the limitations of quantitative indices. A qualitative assessment of water resources in a country differentiates between the types of water available (Falkenmark, 1989). A water scarcity index gauges the level of renewable surface and exploitable groundwater reserves in a country, generated both locally and externally (FAO Aquastat, 2002). The majority of the worlds' food is not grown using this surface & exploitable ground water, but rather soil water trapped between particles in the soil horizons. Irrigated agriculture accounts for 43 percent of world grain production, with soil water supplying the moisture needs of the remainder (Berkoff, 2001). Soil water comprises about 38 percent of the freshwater available on earth (Miller, 1998).

The USA, France and other temperate-zone countries are grain exporters due to their large reserves of soil water, freely available to them as rainfall. Levels of soil water are negatively affected by high rates of evapotranspiration. Therefore, although Johannesburg and London receive similar amounts of rainfall annually, just over 600mm, the former has much lower quantities of soil water than the latter. The temporal and geographical variability of rainfall which many arid parts of the world experience, combined with high levels of evapotranspiration typical in these areas precludes much of the earths' surface from being suited to the growth of rainfed or irrigated grain (Figure 2).

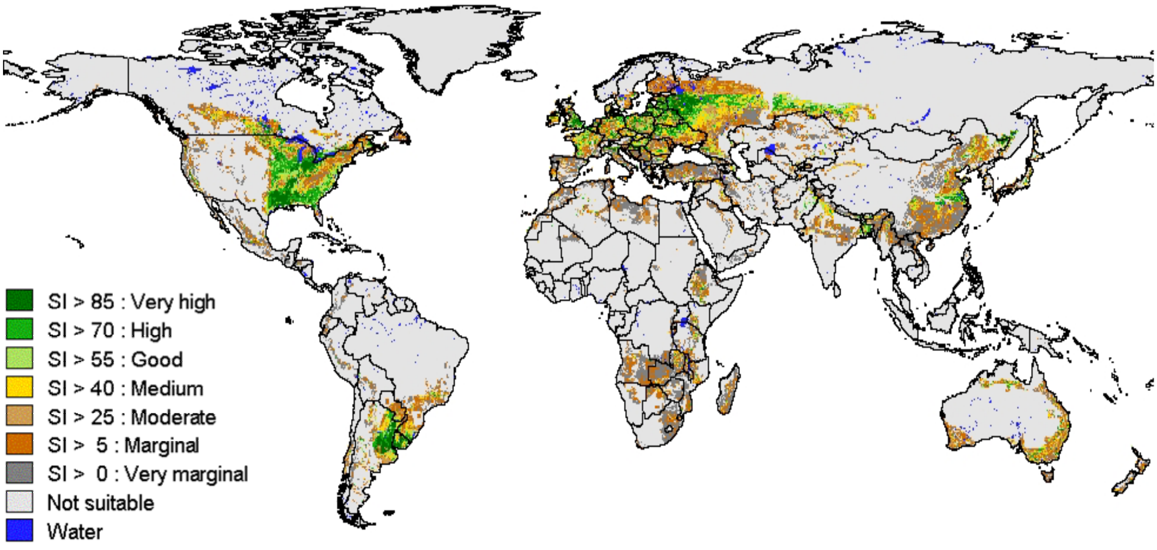


Figure 2. World suitability for rainfed & irrigated wheat – high inputs (IIASA, 2000).

Areas with low levels of soil water can augment their supplies through water transfers and grow crops under irrigation. The high rates of evapotranspiration, over 3700mm annually in parts of Botswana and Namibia compared with a world average of around 1200mm, poses the risk of salinisation to the soils in the arid regions (FAO Aquastat, 2002). Whole tracts of land can be turned sterile by the accumulation of salts left behind as a residue from evaporated irrigation water. From Sumeria to California there are many examples of the devastation caused by injudicious use of irrigation water in arid regions (Postel, 1999). Coupled with the potential dangers of over-irrigation is the fact that achieving a positive rate of return on irrigated grain production can prove difficult (Berkoff, 2001).

Table 1: Water resources in the SADC

	Dependency Ratio	**Water per person**
Angola	0	14,046
Botswana	80	9,600
Congo DR	30	25,182
Lesotho	0	1,485
Malawi	7	1,528
Mauritius	0	1,903
Mozambique	54	11,814
Namibia	66	9,967
South Africa	10	1,155
Swaziland	45	2,854
Tanzania	10	2,591
Zambia	24	10,095
Zimbabwe	30	1,587

Source: FAO Aquastat, 2002

What emerges is a picture of water resources scarcity suited to a particular economic activity. A shortage of soil water indicates that the production of staple grain crops will not be economically viable. Amongst the members of the SADC it is difficult to quantify which countries possess good supplies of soilwater. As can be seen from Figure 2 most of the south and south west of the region is ill-suited to the production of grain (the DRC is classified as unsuitable as it is covered in forests, yet has vast areas capable of supporting rain-fed grain production). Several of these countries have high levels of water resources per person (Table 1). The level of dependency on external water supplies needs to be taken into consideration when assessing water resources in the countries. For instance, Namibia and Botswana rely heavily on water from other countries. The implication is that this water is difficult to utilise for political and economic reasons. Any attempt by Namibia to begin pumping its "equitable share" from the Okavango River draws strong opposition, not just from Botswana but also from international conservation organisations who fear a negative impact on the Okavango Delta (Ashton, 2002 & Turton, 1999). Even if it were politically feasible to use this water, the pumping costs would preclude it from viable use in the production of grain crops. Mozambique is also dependant for over half its water from foreign sources but has such large quantities available to it locally that it does not have to rely much on water originating across the border. Only in the southern regions does it experience water shortages. What emerges is a typology of countries in accordance with their quantity of water available as well as the extent to which they rely on external supplies (Figure 3).

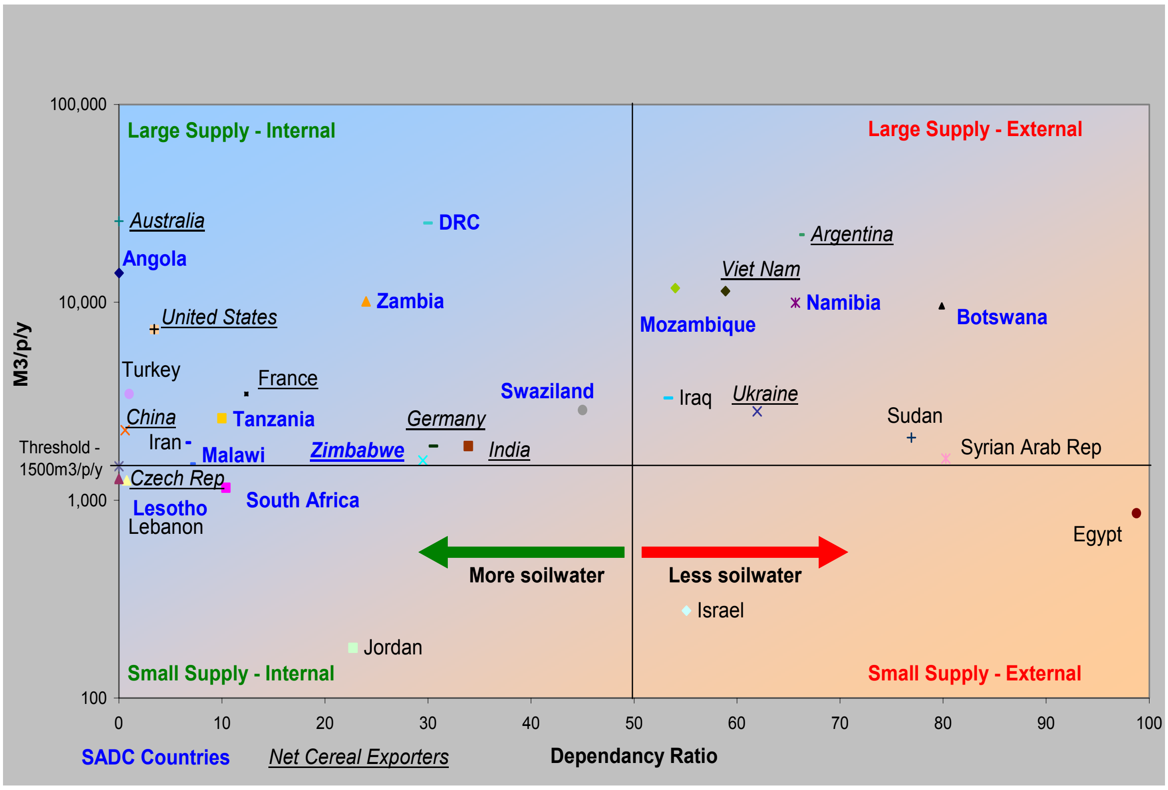


Figure 3. Water resources & dependency of a variety of grain exporting & importing countries

The four classes that countries fall under are:

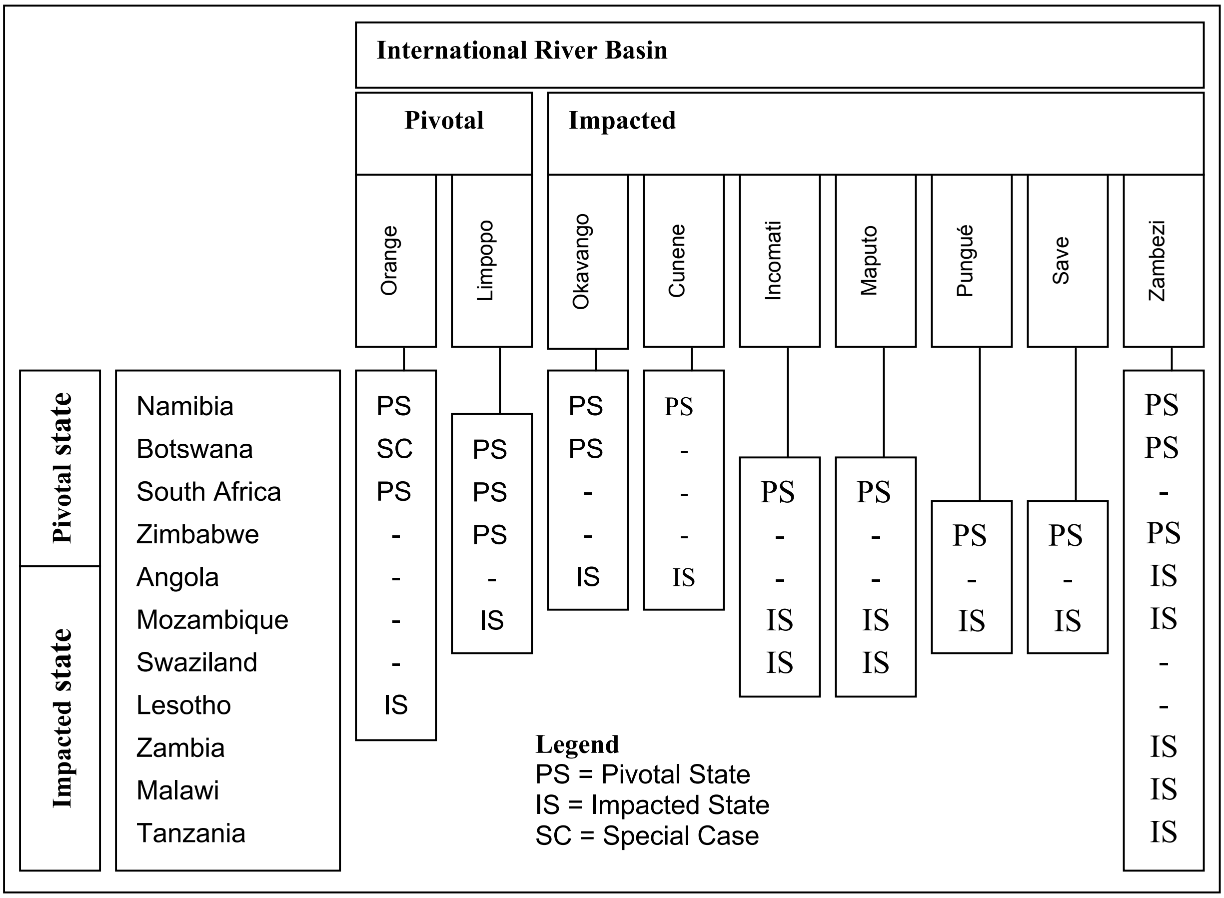
1. *Large Supply – Internal*. These are states that, in addition to having lots of water, also have a high degree of geographic control over their water resources. Levels of soil water are likely to be high, with most of the world's largest grain exporters in this category (USA, France, Germany, Australia).

2. *Large Supply – External.* Several other large grain exporters fall in this category, yet for many of the countries on this list access to the water is difficult for political reasons. States such as Sudan, Syria, Botswana & Namibia have to take into account the claims to water of both upstream as well as downstream riparians when wishing to use water on their territory. Some of these states do have large regions inside them that receive enough rainfall to make them well suited to grain production (Argentina & potentially Mozambique).

3. *Small Supply – Internal*. Although having relatively little water per capita many of these states manage to support a viable agricultural sector as what water they do have originates on their territory. This makes it both politically as well as economically easy to use as it frequently is distributed over regions as reliable rainfall providing high levels of soil water. This explains why the Czech Republic with only 1,200 m3 per person has enough water to be a grain exporter and why a country such as the Lebanon imports roughly half the amount of grain per person than what Israel does (FAO, 2002).

4. *Small Supply – External*. The most vulnerable position to be in as not only is there little water available to each citizen, but the little that there is comes from across the border. Israel and Egypt are two prime examples, with both having to rely on political force and economic might to access sufficient water for grain production.

The concepts of Pivotal and Impacted States and Basins (Turton, 2003) are useful because it enables a nuanced understanding of the hydropolitical dynamics that have a bearing on Virtual Water trade to be developed. Pivotal States are those riparian states within a given international river basin with a high level of economic development that also have a high reliance on shared river basins for strategic sources of water supply. In the context of Southern Africa, there are four states in this category - the Republic of South Africa, Botswana, Namibia and Zimbabwe. These states are all either water scarce, or are heavily reliant on external water supplies. Pivotal Basins on the other hand are those international river basins facing closure that are also strategically important to any one (or all) of the Pivotal States by virtue of the range and magnitude of economic activity that they support. In the context of Southern Africa, there are two basins in this category - Orange and Limpopo. Impacted States are those riparian states that have a critical need for access to water from international river basins shared with a Pivotal State for their own economic and social development, but by virtue of the unequal power relations within the basin concerned, are unable to negotiate what they consider an equitable allocation of water. In the context of Southern Africa, there are seven states in this category - Angola, Mozambique, Swaziland, Lesotho, Zambia, Malawi and Tanzania. These states either have abundant water resources, or are not heavily dependant on external water supplies, making them hydro-logically secure. Impacted Basins are those international river basins that have at least one (or more) of the Pivotal States as co-riparians, which in turn reduces the freedom of choice for the Impacted States to develop their water resources in a manner that they deem to be fair and equitable. In the context of Southern Africa, there are seven basins in the category - Zambezi, Cunene, Okavango, Incomati, Maputo, Pungué and Save (Figure 3b).



		International River Basin								
		Pivotal		Impacted						
		Orange	Limpopo	Okavango	Cunene	Incomati	Maputo	Pungué	Save	Zambezi
Pivotal state	Namibia	PS		PS	PS					PS
	Botswana	SC	PS	PS	-					PS
	South Africa	PS	PS	-	-	PS	PS			-
	Zimbabwe	-	PS	-	-	-	-	PS	PS	PS
Impacted state	Angola	-	-	IS	IS	-	-	-	-	IS
	Mozambique	-	IS			IS	IS	IS	IS	IS
	Swaziland	-				IS	IS			-
	Lesotho	IS								-
	Zambia									IS
	Malawi									IS
	Tanzania									IS

Legend
PS = Pivotal State
IS = Impacted State
SC = Special Case

Figure 3b. Typology of international river basins in the SADC.

The significance of these concepts is that they explain the nature of the political and economic relationships that exist between various riparian states in international river basins. The possible future trade in Virtual Water is affected by these existing hydropolitical factors. For example, Mozambique is a potential virtual water exporter, by virtue of its relatively favourable natural precipitation pattern. In reality however, Mozambique is an Impacted State with relatively little room for manoeuvre, being politically and economically dominated by South Africa and Zimbabwe, both Pivotal States, and both being upstream riparians to Mozambique on various international river basins. Similarly, the importation of Virtual Water requires a foreign exchange surplus with which to fund the purchase of cereals. Zimbabwe, as a potential Virtual Water importer, has a foreign currency deficit, and is simply unable to pay for such purchases. This creates something of a black hole within SADC, as it militates against the ‘normalization’ of Virtual Water trade within the region, while ‘exporting’ political and economic instability at the same time.

Water flows and transfers

The SADC states with large supplies of internally generated water all have GDPs of US$ 300 per person or less, placing them in the category of least developed nations. The rich SADC states, with GDPs per capita of US$ 2,500 and above, are either dry or heavily reliant on external water sources. There has been very little exploitation of this disparity between states of water resources and income levels. One of the few schemes designed to cash in on this disparity is the Lesotho Highlands Water Project that exports water to South Africa. As the impacted state Lesotho probably had few alternatives open to it other than cooperating with its more powerful neighbour, yet the project does provide a useful cash inflow for Lesotho. It is likely that in the future more of the water stressed rich states in the region will be interested in developing water transfer schemes from the water abundant poorer sates such as the DRC, Zambia and Angola. Pipelines and canals from rivers in these states, such as the Congo, the Zambezi and the Lualaba, can provide an extra 7 – 8 km3 per year to the industrial areas of Botswana, Zimbabwe and South Africa (Heyns, 2002).

Such schemes do have many drawbacks, including the high construction and operation costs (the water would have to be pumped over higher ground), environmental consequences and political insecurity. Using the LHWP as an example, these problems can be quantified. The first phase of the LHWP has been completed and supplies 0.5 km3 to South Africa annually, providing Lesotho with an income of about US$ 1.5 million per month (TCTA, 2002). To date the project has cost US$ 1.5 billion, borrowed mainly from the World Bank. The capital costs of this project are high, but the operational costs are low as the scheme relies on gravity to transport the water to South Africa. For this reason, it is cost effective over the long term. A transfer scheme from the Congo or the Zambezi rivers would cost considerably more to build as it would have to cover over 2000 km and the operational costs would be much higher due to the electricity which has to be used in pumping the water over higher ground. Electricity generation is already the main industrial user of water in South Africa and any increase in generating capacity would most likely be accompanied by a greater water demand, bringing lower returns to the overall investment. Large-scale water transfer schemes can be effective where there is an energy surplus. For example, the Thukela Water Project in South Africa transfers water from the Thukela River, across the Drakensberg Mountains, into the Vaal River by using off-peak surplus electricity. The unused surplus energy is thus transferred to the water, which is stored in a dam at high altitude, and a significant portion is recaptured when the national grid is in energy deficit by releasing the stored water into the Vaal River system. The existence of an energy surplus is generally not a characteristic of other parts of SADC, thereby making water transfers in those areas economically unfeasible.

The LHWP has also caused a range of social and environmental side effects due to people relocating as the dams filled up. More people trying to use the same land for cattle grazing has led to serious soil erosion problems in the Highlands region, to the extent that the Government of Lesotho has, belatedly, decided to involve communities in watershed management initiatives (LHDA, 2002). In this case the environmental side effects were expected and can probably be rectified with a minimum of effort and cost.

In Namibia the 260 km long Grootfontein-Omataka canal forms a component of the Eastern National Water Carrier (ENWC). Since being completed it has gained a reputation as a "death trap", due to the large number of wild animals that fall into it. According to the one of the current directors in the Namibian Department of Water Affairs "it is doubtful whether a full environmental assessment would have identified such an impact because no other example of this nature exists in the world" (Heyns, 2002: p175). The very nature of water transfer schemes make them difficult to assess environmentally as each project is unique, crossing through several different environmental sub-systems. It is likely that there will always be an element of uncertainty regarding the possible environmental consequences of such schemes.

Another problem of large water transfer schemes in semi arid regions is the massive loss of water due to evaporation. For example, evaporative losses from the ENWC in Namibia are in the region of 70% (Davies *et al.,* 1993:168). The transfer of water between basins also introduces alien biota with potential devastating ecological impacts (Davies *et al.,* 1993:167). These unintended consequences of inter basin transfers add considerably to the overall complexity that needs to be managed, detracting from their potential advantages in the long-term.

The potential virtual water flows within the SADC

The alternative to water transfers is to stimulate trade in water-intensive products. According to the Heckscher-Ohlin Factor Equalisation model, international trade is driven largely by differences in countries' resources, or factors of production. It implies that trading in goods is an indirect way of trading in the factors of production used intensively in their manufacture (Krugman & Obstfield, 1995). Therefore trading in grains, which are very water intensive using up to 1300 tonnes of water for every tonne of grain produced, is an indirect way of trading in water between countries (Kreith, 1991). Instead of investing in water transfer infrastructure focus can be placed on enabling those countries in the SADC that are suited to the production of grains to become effective producers with good transport systems available. Angola, Mozambique, the DRC and Zambia have the potential to become the breadbaskets of the region, receiving infrastructural investment from the Pivotal States in the region in return for grain. The long-term effect would be to stimulate economic development and job creation in these Impacted States and ease the water stress faced by the water-scarce states. The potential grain suppliers to the region are all large Impacted States with a vast amount of internally generated water resources (apart from Mozambique that does rely on external water, yet is included due to its large amount of local water). Together, this group, comprised of Zambia, Mozambique, the DRC and Angola have a population of about 90 million out of 200 million in the SADC (SARPN, 2002).

The next group is comprised of the economically powerful Pivotal States that are water insecure, including South Africa, Botswana, Namibia and Zimbabwe (see Appendix, Chart 6 for GDP figures). These are potentially the largest importers of virtual water in the SADC for two reasons. They have reached the limit of their economically viable water resources and they have high enough levels of second-order resources (institutional, economic & human capital) to use water in the sector of the economy where it will generate the most income. The final group includes Malawi, Lesotho, Swaziland and Tanzania and comprises the countries with relatively limited future grain production expansion potential and with low levels of second-order resources. Either these countries do not have sufficient water supplies, including soil water, or have poor quality soils and terrain not suited to large-scale grain production. This does not preclude other agricultural activities from being possible as a range of horticultural products as well as intensive small-scale food crops can be grown.

At present, the countries with the potential to become suppliers of grain in the SADC are all net food importers (Figure 4a & 4b).

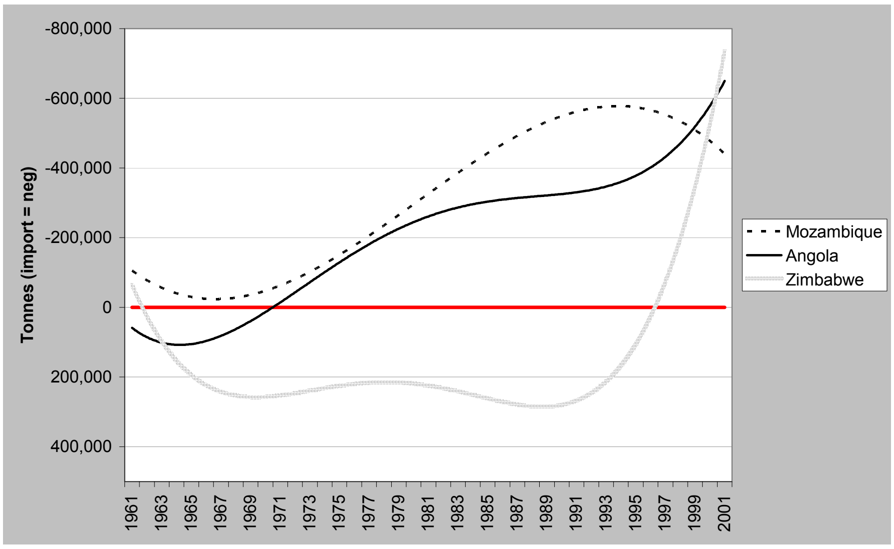


Figure 4a: Grain trade balance in SADC countries (smoothed trend line)

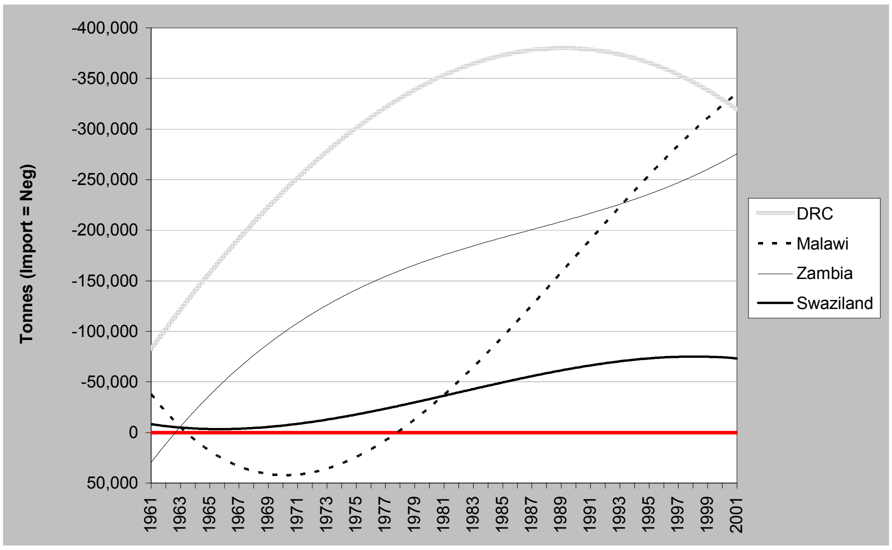


Figure 4b: Grain trade balance in SADC countries (smoothed trend line)

The main reason for the reliance on grain imports by these countries has to do with their state of second-order resources. Angola, the DRC, Zimbabwe and Mozambique are all either entering or emerging from civil conflict. Zambia, Malawi and Swaziland all have very low incomes per person posing problems for agricultural development. This can be seen clearly in *Mozambique*, as grain production has risen steadily since the peace process began, with indications that the country may become a net food exporter within the next five years (see Appendix, Chart 1). The northern sections of the country have a 100,000 tonne grain surplus for 2002 and have exported a small amount of grain to Kenya (FAO 2002b). High internal transport costs make it cheaper to rely on imported grain for the food deficit southern sections of the country that have experienced drought conditions over the past two years. These southern and central regions were also the hardest hit by the floods of 2000 and 2001 which, coupled with diminishing returns from migrant workers on South African mines, means that most drought coping mechanisms have been depleted. The bulk of the grain imports are covered by commercial sources with a US$ 50 million shortfall to be covered by food aid (see Appendix, Chart 5).

In Mozambique the most important contributing factor to the current food insecurity is the state of the transport infrastructure of the country. Most of the transport routes cross the country laterally, from west to east serving as transport corridors for South Africa, Zimbabwe and Malawi. Both prior to and after independence the longitudinal transport routes in this “long” country have not been developed. With various new industrial developments earning foreign currency the country’s reliance on food aid looks set to decrease. There is a large potential for a trade in virtual water within the country as most of the industrial development, such as the Mozal aluminium smelter outside Maputo, is taking place in the water-scarce south of the country. The central floodplains and northern lowlands have the right climate and soil for large-scale grain production. The total cultivable area is estimated at 36 million hectares, of which only about 15 percent is currently cultivated (FAO Aquastat, 1995). Once the north-south transport routes improve, the southern regions of the country will be able to devote more of their water resources to the industrial sector, relying on grain “imports” from the north. In many respects Mozambique holds out the best hope over the short to medium term of becoming a regional grain provider as the benefits of a decade of peace and the accompanying development combine with favourable geography for continued agricultural expansion.

The *DRC* has vast tracts of land with suitable rainfall and good soils which could see massive agricultural development. Subsistence farmers are able to occupy land once it is vacated by rebel forces contributing to a steady rise in the production of grain (see Appendix, Chart 1). Renewed outbreaks of fighting during 2002 have disrupted agricultural activities in several regions with many people forced to vacate their land. Coupled with the lack of transport infrastructure and the low rate of industrial development many people in the country are food insecure. This country has the potential to supply all of the grain requirements of the SADC, but with the current transport and political problems this is a medium to long-term objective at best.

Angola has slowly managed an increase its grain production since the peace process started in the 1990’s (see Appendix, Chart 2). As the government has gained more control over the diamond and oil industries there has been an increase in the amount of commercial grain imports while keeping its reliance on food aid constant, with financial aid per person halving since 1996 (see Appendix Chart 5). With the implementation of the recent peace agreement and the demobilisation of UNITA forces food imports have had to be increased in order to feed the internally displaced population who have not yet been able to start working the land (Grobbelaar et al, 2002). If the demobilisation process is successful and the peace agreement holds the agricultural production potential of the country is large. Yet again the main obstacle to it becoming a major grain supplier to the region is the poor state of the transport infrastructure. It costs more to supply grain from the hinterland to the port city of Luanda than it does to ship it from the USA (Grobbelaar et al, 2002). In the medium term there are good prospects for re-establishing the agricultural production in the southern areas of the country and improving the road network enabling exports to Namibia and Botswana.

The second largest recipient of donor food aid for the 2002/2003 season is *Zambia* at about 225,000 tonnes (FAO, 2002b). Yet this is another one of the countries, which have a large supply of internally generated water available. As can be seen from Figure 4b the country is relying increasingly on imported grain. Part of the reason for this is the increase in the production of high value horticultural crops such as vegetables for the export market. These exports provide much needed foreign currency and were the cause of debate recently when the WFP tried to supply Zambia with GM food aid. While it is not known whether GM foods pose a health risk it is a fact that the EU is very strict about letting in GM products due to consumers not wanting them. An example of this is the drop in US maize exports to the EU from US$ 426 million in 1995 to US$ 1 million in 1999 (Patel & Delwiche, 2002). The Zambian government feared that having GM maize in the country might lead to an embargo by the EU on its agricultural products, delaying the distribution of food aid into the country. Issues such as this point to the need for a homogenous food and agriculture policy for SADC states with an emphasis placed on stimulating internal trade. There is a large potential for the expansion of the agricultural sector in Zambia as at present only about 7 percent of the cultivable land is in fact cultivated. The transport infrastructure is of a high enough standard to allow rapid delivery of grain to countries in the region.

From a geographic point of view the climate and the terrain are not as well suited to grain production as the other three potential producers, but it does benefit from having a more developed agricultural sector as well as better transport infrastructure. Chart 1 in the Appendix shows the annual variability in the Zambian grain production, with output heavily reliant on weather systems. Irrigated agriculture would have to play a greater part in the future agricultural development of the country.

Together the above four potential grain exporters have a cultivable area estimated to be about 162 million hectares, taking into account soil suitability and water availability (FAO, 1995). Mozambique makes the largest use of its cultivable land, using 15 percent, whereas between 5 and 8 percent is used in the other countries. If this were increased by only ten percentage points and used to produce grain at a, very, low rain-fed yield of 1 tonne per hectare it would amount to 16 million tonnes, roughly double what the region currently imports. It is probable that these countries could produce grain at a price that can compete with the low world grain prices currently prevailing on international markets. Most of their water is free and labour costs are lower than in the EU and the USA. Such a simplification does not take into account the various factors hindering an increase in production in these countries, as well as the transport and storage problems but it does serve to show that the production potential exists within the SADC. Each of the above is an Impacted State, which weakens its overall hydropolitical position vis-à-vis other riparian states in various international river basins, so it remains trapped in a series of unequal power relations that continue to hamper development.

The second group of countries are the economically powerful, water scarce ones – South Africa, Zimbabwe, Namibia and Botswana, who are all increasingly reliant on grain imports (Figure 4c & 4a). These are also Pivotal States with a high reliance on shared water for their future economic growth and survival, which means that their hegemonic status is likely to become a bigger factor in future, particularly to the detriment of co-riparians in Pivotal Basins or Impacted Basins.

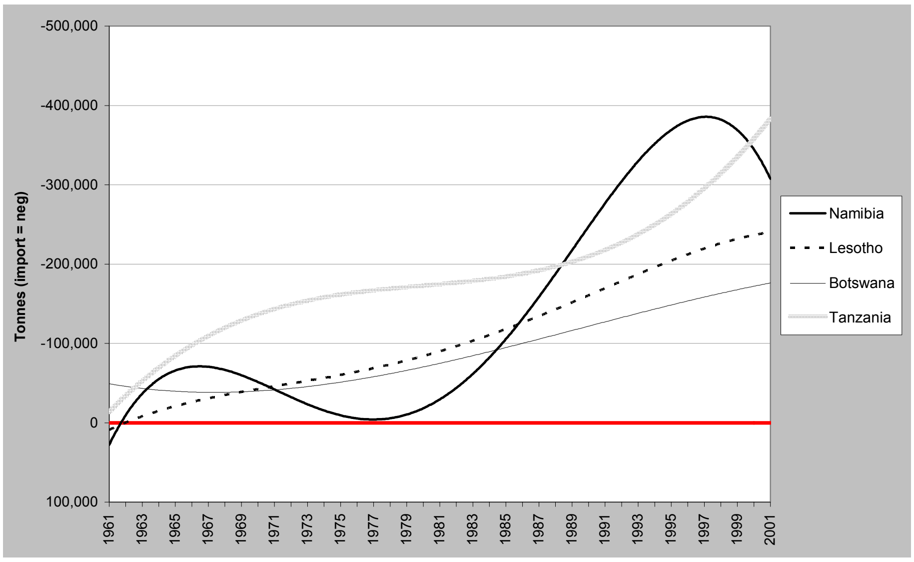


Figure 4c. Grain trade balance in SADC countries (smoothed trend line).

Production in *Zimbabwe* has always been highly variable as the country produces most of its grain under rainfed conditions, relying on the changeable weather systems in the region (see Appendix, Chart 2). This cycle of dry years and wet years is reflected in the food aid flows to the country with increases during the 1983/1984 drought as well as during the 1991/1992 drought (see Appendix, Chart 5). The current food crises is greater in extent and depth of hunger, with very few coping mechanisms being available to people. It has also had a notable effect on residents in the urban areas of the country due to the economic downturn (FAO, 2002a). This contrasts with the earlier emergencies, which were largely confined to the rural areas of the country. The current reliance on grain imports is partly caused by disruption to the commercial farming sector from the land redistribution policy of the governments. Another contributing factor was the liberalisation of the economy in the early 1990s with producer and consumer price support mechanisms being removed. Tariffs on imported grain were steadily reduced, causing farmers to start focussing more on higher value crops such as tobacco. This had a positive effect on water consumption with the new water act introducing charges for agricultural water and user licenses. The country's water resources are extensively developed with many dams and water irrigation schemes in place, with the country moving towards a state of absolute water scarcity (Derman, 1999).

As recently as 1996 the country was considered one of the regional economic powerhouses as it has a diversified economy with a strong manufacturing sector. Agriculture was playing a smaller role in the economy especially as competition for water started intensifying from other sectors. With the present instability in the country it is difficult to predict how it will progress. Will Zimbabwe recover, rebuild its economy and continue developing, relying increasingly on virtual water to ease its water shortages or will it become one of the marginal states in the region which struggles to feed itself and does not have a high enough level of second-order resources to import enough grain for its people? In many respects it is a pivotal state not just from an economic or political point of view, but also because of its effect on its neighbours. The country has been involved in the DRC war and could become instrumental in ensuring that peace takes hold in that country. There is also some evidence that the recent famine in Malawi was exacerbated by the instability in Zimbabwe as it slowed down food supplies from South Africa to Malawi (Devereux, 2002).

The food supply per person in *Botswana* has increased steadily since the late 1970's when it started cutting back on agricultural production (FAO, 2002). Currently the country produces about half as much as what it imports with no indication that it may change (Figure 4c & Appendix, Chart 3). Of all the states in the SADC it most relies on virtual water to augment its sparse local supplies. Mining and tourism earn foreign currency for the country with most grain then imported from South Africa, who most likely also imports it. Although it is a small country (population of about 1.5 million) it is likely to continue to provide a good market for grain from the region as the economy continues to grow.

The situation is very similar in neighbour *Namibia*, also an affluent country with a small population and very little accessible water suitable for use in grain production. It does have a strong cattle export industry, principally to the EU, which it feeds mainly on imported grain, most probably from the EU. Although sounding like a circular argument it is economically efficient, as a steak needs 16 times more water to produce than the same mass of grain does, if all the feed inputs are taken into account (Kreith, 1991). Grain, subsidised by the EU taxpayer is used to produce cattle that are exported to the EU under a preferential trade agreement (Hewitt & Page, 2001). If the country can maintain its beef market share in the EU but use regionally grown wheat the benefits will be felt by its northern neighbours.

The odd one out in the SADC is *South Africa*, as not only does it have an economy larger than that of all the other members combined (US$ 128 billion out of US$ 183 billion of the SADC) but it is also the only country that has been a major grain exporter in the region (see Figure 4d).

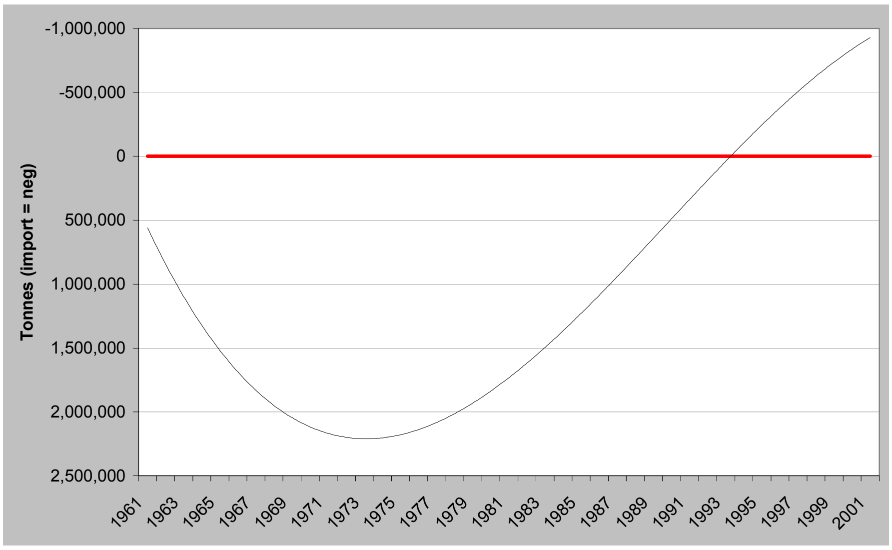


Figure 4c. Grain trade balance in South Africa (smoothed trend line)

Since the large drought the country experienced in the mid 1980s it has relied increasingly on food imports, with local grain production slowing and accounting for less of the output of the SADC (see Appendix, Graph 4). South Africa, now freed from the trade impediments and forced national self-sufficiency in food that were a characteristic of its international pariah status, is in a position to shift its policy towards one of food security instead. This is already happening, and can become a window of opportunity for intra-regional trade in Virtual Water. Agriculture accounts for an ever smaller share of the South African economy, dropping from 12 percent in the early 1980s to less than 4 percent today (AGRIC-SA, 2001). The composition of the agricultural crops has also changed from being focussed on the production of grain crops to diversifying into the production of high value crops for export such as organic vegetables, fruit and flowers (AGRIC-SA, 2001).

The above four countries represent the principle markets for virtual water in the region. Apart from Zimbabwe, there is the ability to pay for grain, allowing local water supplies to be used in more water efficient sectors of the economy. As the Pivotal States in the region they are in a position to dictate their relationship with the Impacted States and will be able to implement water transfer schemes to augment their scarce water supplies.

The other four countries of the region, *Lesotho, Malawi, Swaziland* and *Tanzania*, are Impacted States characterised by low levels of water resources, and geography ill suited to large-scale grain production. Tanzania saw large increases in grain production during the 1970's with the development of various irrigation schemes around the country (see Appendix, Chart 2). By the late 1980s many of these schemes were not operating, with people reverting to rain-fed production in response to low international grain prices (Berkoff, 2001). Malawi relies on tea and coffee exports to earn foreign currency and imports most of its grain needs, although there is strong production of grain in the subsistence sector. Most of this is rain-fed, making it vulnerable to drought, as was seen in 2001/2002. Subsistence agriculture is very important in all four of these countries, yet the rural population are all net food consumers, having to augment their production with purchases of grain in most years. They would benefit from an increase in the regionally traded virtual water, as supplies should be available from neighbouring countries during times of drought.

Impediments to virtual water trade in the SADC

An increase in intra SADC virtual water trade holds several benefits to the countries in the region. To the potential breadbasket nations investments in their agricultural industries and transport networks by the Pivotal States will stimulate economic development. Water transfer schemes provide temporary construction jobs and a few operation and maintenance jobs but very little beyond this. Whereas investments in setting up the infrastructure for commercial farming would provide long-term and sustainable employment to a large number of people. More of this infrastructure is likely to be "dual-use" than that involved with building a transfer scheme, as roads would have to link supply areas with the markets. Water transfer schemes also have the disadvantage of locking the supply country into a long-term exclusive arrangement with a Pivotal State. Revenues from the transfer of water will be dependant on the demand from these water-scarce states, as it is not possible to switch to another market. Once the countries start producing a grain surplus there are a variety of markets to which they could sell their product. Even if the original grain importer countries in the region decide not to import any more grain from the supply countries there are still many other international and regional markets open to them, although trade barriers can make access a problem.

The water-scarce Pivotal States stand to benefit from investments in stimulating regional virtual water trade. The cost of investing in grain production and transportation infrastructure is likely to be much lower than that needed to build and operate the very large long distance water transfer schemes proposed. There is also the added level of national security in not being dependant for water on one or two other countries. A souring of relations between the water supply and water demand nations could see water transfers being used as leverage against the Pivotal States. Relying on virtual water has the advantage that there are several possible sources of supply available, with transaction costs on the international grain markets relatively small. This is important as no matter how economically efficient the concept of virtual water is regionally, it will not succeed if it does not take cognisance of the political balance of forces within the region. The Pivotal States do not want to be in a situation where a strategic resource, such as water, falls under the control of state over which it does not have political and economic control currently. The Impacted States are not going to want to enter into a relationship with a Pivotal State that makes them highly dependant on income from an exclusive market. This is why the only large inter-state water transfer scheme in the SADC is between South Africa and Lesotho. As was seen during the coup attempt in Lesotho of 1998 there was drastic rapid and force-full military action from South Africa and Botswana, both dependant on water from the LHWP, in order to protect LHWP infrastructure. A similar scenario in the DRC or Angola would be much more difficult to bring under control and would pose a real threat to any water transfer infrastructure.

One of the serious impediments to intra-regional Virtual water trade is the skewed pattern of existing regional trade, with most Southern African countries being locked into unfavourable trading partnerships with their erstwhile colonial masters. This is a real impediment with a long history of deeply entrenched interests that will not be easily broken. At present the volume of intra SADC trade is roughly half that of the trade between SADC states and other countries, mainly the USA, EU and Japan (SADC, 2001) There are also political sensitivities within SADC, with many of the member states having only recently gained their political independence, so notions of a new type of economic dependency may easily be labelled as neo-colonialism and be given an unpalatable political flavour. The Impacted States are wary of any development initiatives driven by the Pivotal States and would not want to be locked into trade arrangements with them. If the water-scarce states were to invest in grain production and transportation infrastructure in the Impacted States it would lead to a degree of reliance by the latter on the former. Even though they will produce a product for which there is a world market it may prove to be difficult to gain access to that market. The Pivotal States are likely to only fund transport infrastructure development that would give access to their market. Both the DRC and Zambia are landlocked with the Angolan interior having very limited access to the west coast ports, causing them to rely on transport routes through the Pivotal States. These political issues will need to be overcome in order to encourage development and virtual water trade within the SADC.

There are also economic hurdles to overcome, most notably the effect of low international grain prices. It has been proposed that low prices are in fact a greater impediment to agricultural development than what water scarcity is (Berkoff, 2001). The last half of the 20th century saw an unprecedented drop in real grain prices worldwide (Figure 5a). The principle reasons for these low prices are:

- *Efficiency Gains* - production has increased in relation to world population, with 25 percent more grain available per person in 1998 than in 1961 (Berkoff, 2001 & World Bank, 2001).
- *Trade Barriers* – this includes agricultural support measures, export subsidies and import tariffs and have the net effect of increasing production in the developed world, lowering international grain prices.
- *Food Aid* – in years when the grain price is low food aid donations from developed countries serve to support the prices in those markets, while depressing prices further in the aid recipient markets. When grain prices are high, due to a lack of supply, food aid shipments are also drastically reduced (Figure 5b).

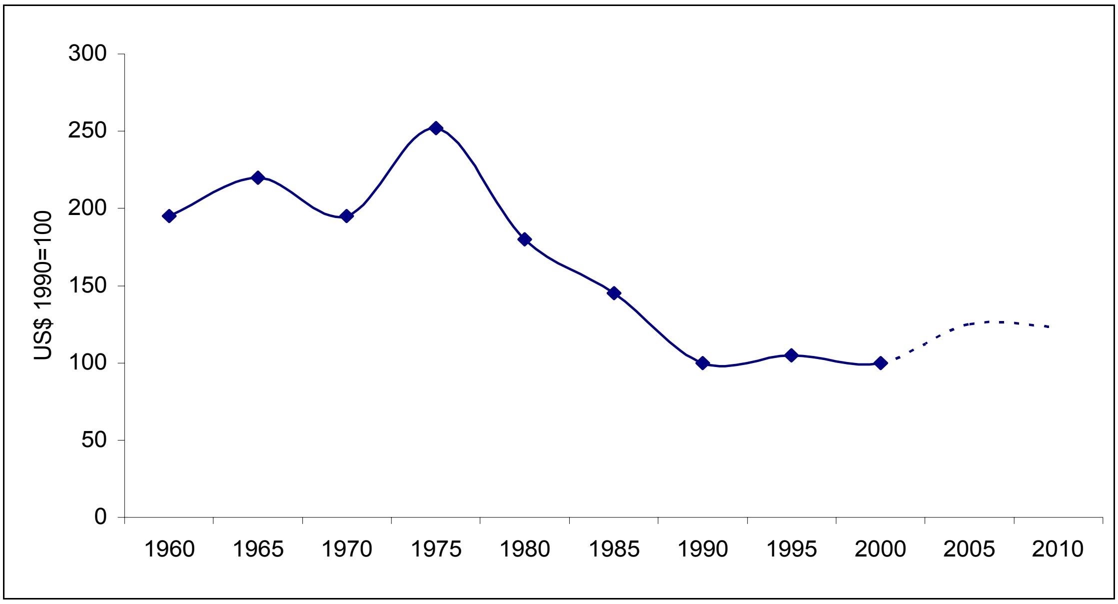


Figure 5a. World grain prices per tonne (World Bank, 2001)

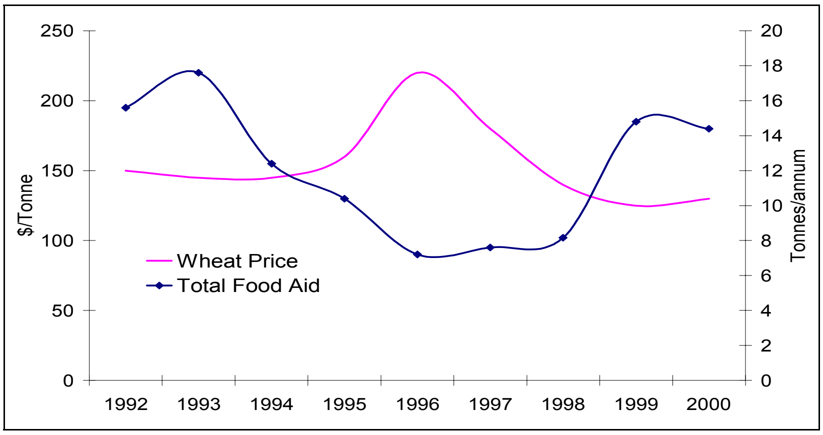


Figure 5b: World wheat price and food aid shipments (ABARE, 2001b)

The effect of these low world prices for grain is that farmers take the rational decision of not making high capital investments in their farming operations. For the small-scale farmer in the developing world it means that at such low prices it is not worthwhile spending money on irrigating the fields or using fertiliser. Yields typically stay very low, with harvests wiped out in drought years. The rural population becomes dependant on food aid or they move off the land and take jobs either on commercial farms or in the urban areas.

This makes it very difficult to produce grain at a profit. If inputs are expensive it is not at all certain that the cost of production will be under the prevailing world market prices. The only way for grain production in the SADC to be competitive with imports from outside the region is if the water is supplied at low or no cost. This makes large areas of the potential breadbasket nations suitable, as the level of soil moisture there is high due to the rainfall patterns. However, what they do not have is the ability to subsidise their agriculture to the same extent as OECD countries do. It has been estimated that total subsidies to farmers in these countries amount to just under one billion US$ per day (OECD, 2002). For the SADC countries intending to invest in production and transport infrastructure as well as inputs such as fertilizer in the potential supply states it may be difficult to realise an economic return on their investment. The rate of return on the investment is always going to be limited by the low marginal cost of grain. Whereas a water transfer scheme provides water that could be used in high value economic processes, adding more to every cubic meter of water consumed than what is saved on imports of regionally grown grain. However, as agriculture currently uses most of the water resources available in the Pivotal States (only in Botswana does agriculture account for less than 50 percent of the water consumed at 48 percent) there is potential for greater water savings in this area. The effect would then be to free up water supplies to be used in more efficient sectors of the economy. The advantage is that the industries of the country then rely mainly on local water, or water supplied by secure Impacted States.

Conclusion & discussion

The above analysis has presented the situation in the SADC regarding water scarcity and dependency. This was analysed from the point of view of Pivotal States vs. Impacted States and Pivotal Basins vs. Impacted Basins. The current amount of virtual water traded within the region is very small, yet there is evidence that some of the states may in the future supply the region with grain. That this has not happened yet has much to do with political instability and a lack of second order resources within the countries concerned. The proposition is made that investing capital in increasing the trade of virtual water within the region holds many benefits over water transfer schemes. These benefits include economic, environmental and political dimensions.

If pivotal states were to make investments in the potential breadbasket states in order to stimulate grain production, the returns to capital would have to make it economically viable. Over and above the initial investments that would need to be made to set up large-scale commercial farms and to build transport routes, which can provide access to the markets, running costs would also include inputs such as fertiliser. For the development scheme to be sustainable the grain provided would have to be at prices lower than the alternative imports from other parts of the world. Three principle areas of further research need to be looked at in more depth:

- What is the rain-fed grain manufacturing potential of the proposed breadbasket states (Angola, DRC, Mozambique and Zambia)? This would have to be seen to be large enough as well as stable enough to supply the region at a low cost.
- What is the ability to pay of the grain recipient countries, specifically he Pivotal States (South Africa, Botswana, Namibia and Zimbabwe)? A large enough market must exist to absorb all the grain produced, as well as paying for the initial infrastructural development.
- Will grain produced in the region ever be able to compete with the low priced imports from other parts of the world?

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Appendix

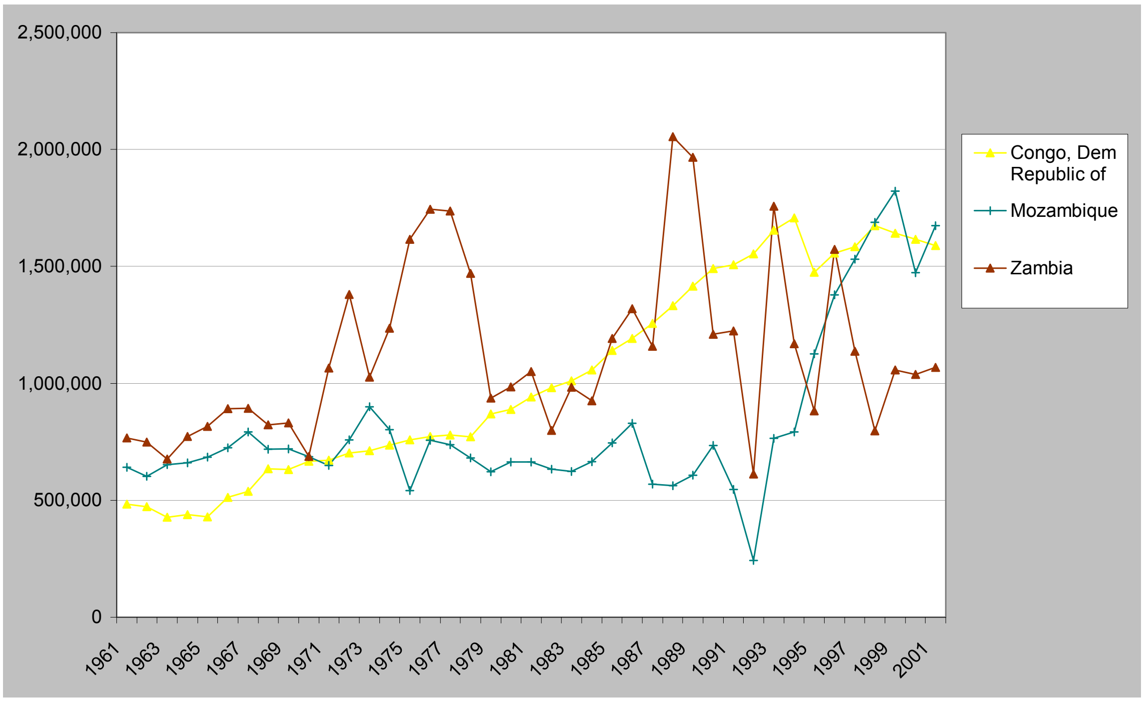

Chart 1. Grain production in the SADC.

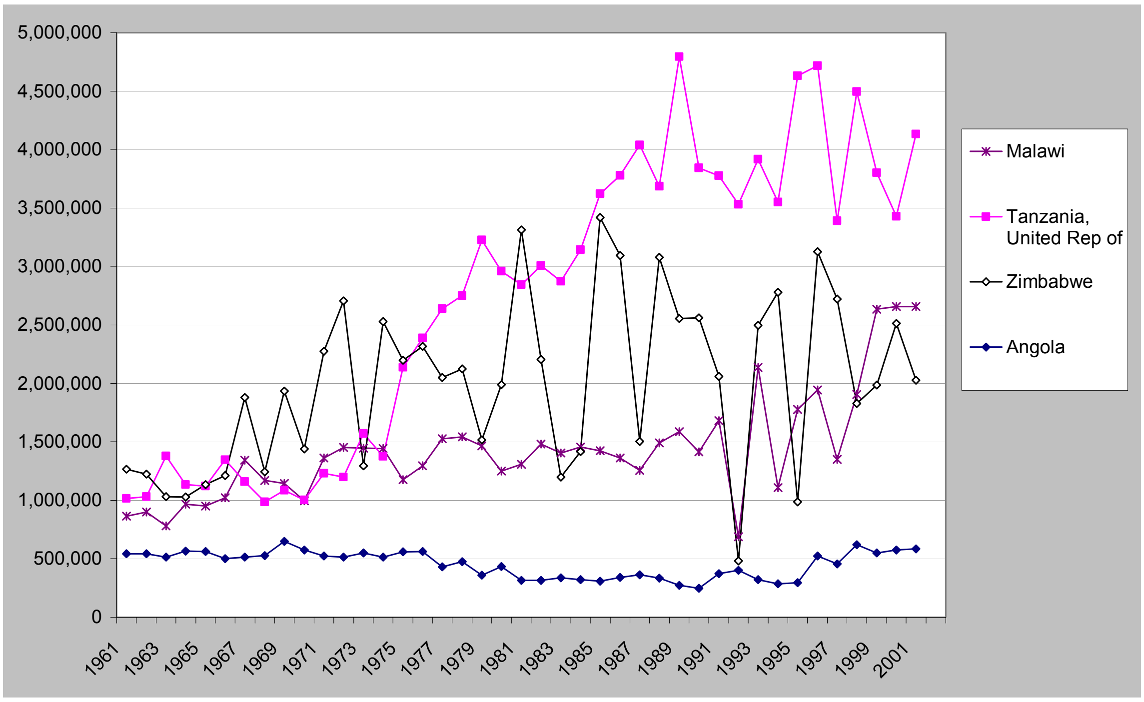

Chart 2. Grain production in the SADC.

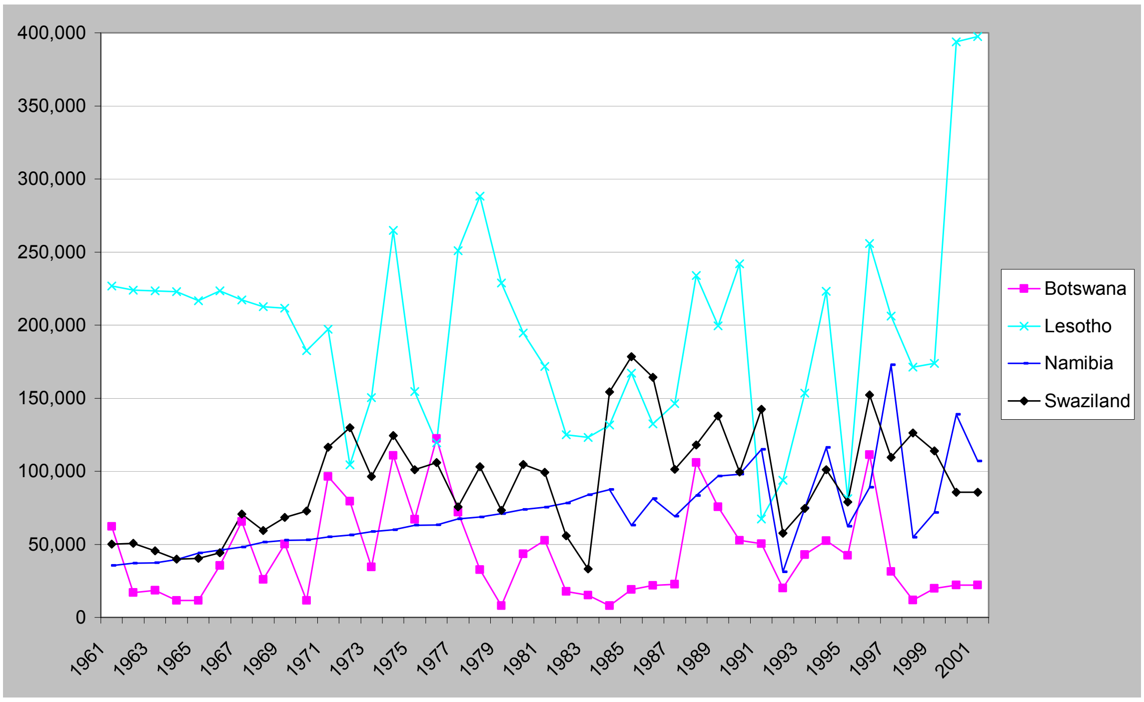

Chart 3. Grain production in the SADC.

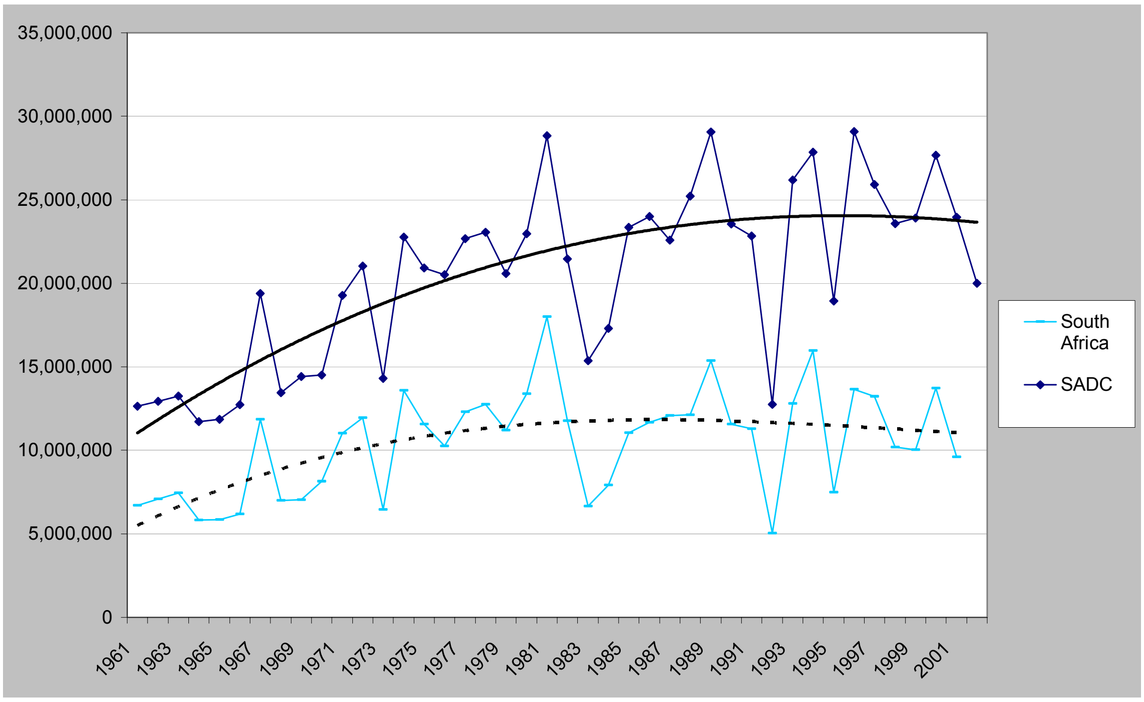

Chart 4. Grain production of South Africa & SADC total.

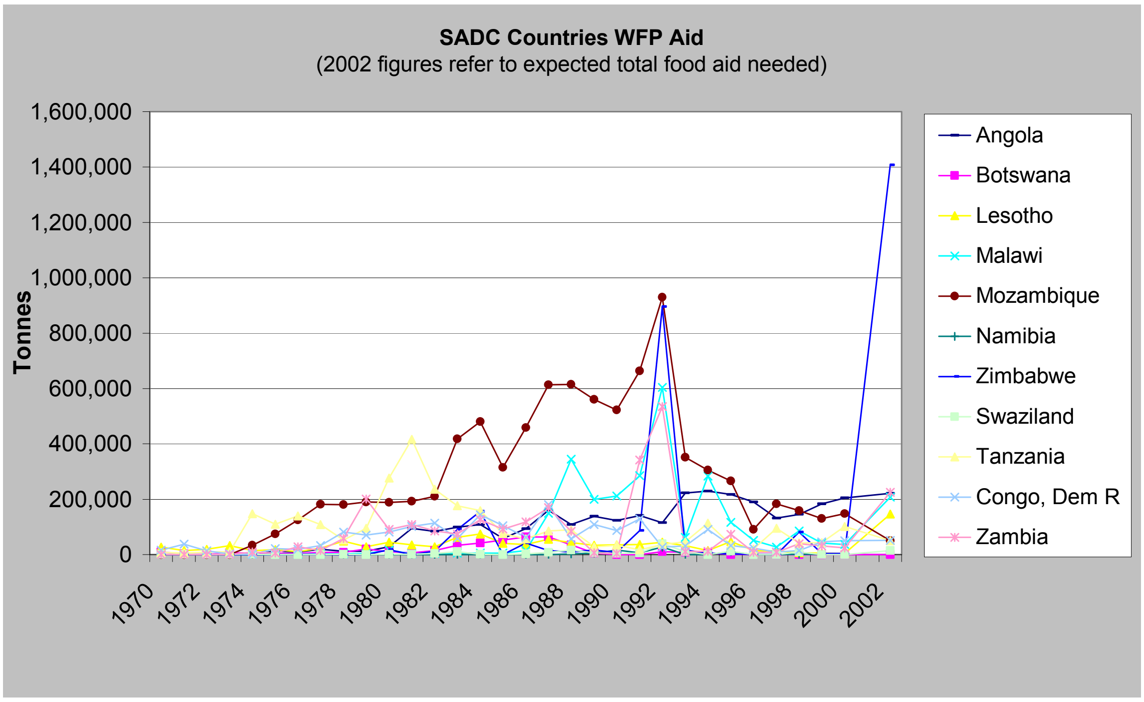

Chart 5. Food Aid from WFP to the SADC.

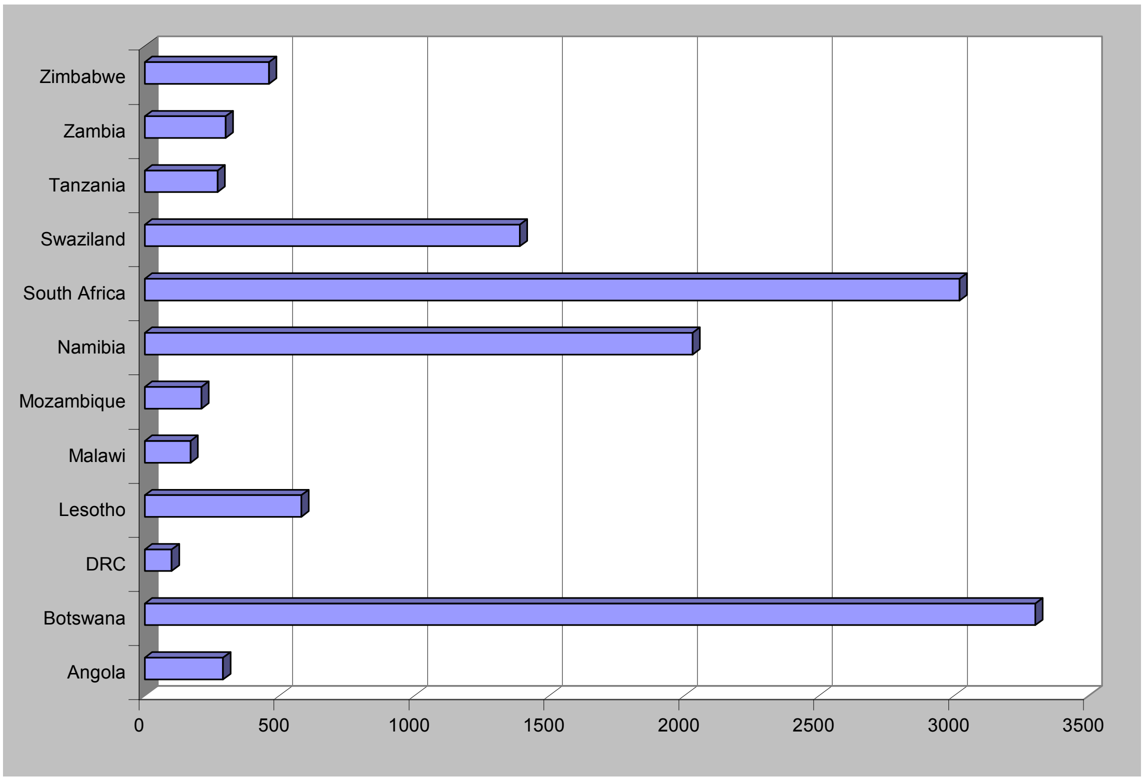

Chart 6. GDP in US$ per person in the SADC (SADC, 2001).

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Regional food security and virtual water: Some environmental, political, and economic considerations

R. Meissner

1. Introduction

The concept of virtual water and the trade therein seems like an enigma wrapped in a mystery. Scholars in a number of disciplines, from International Relations to Sociology, when first confronted by the concept do not understand it, or, at best, do not know what to make of it. Nonetheless, when explained, the concept is more clear and analysing aspects surrounding virtual water becomes second nature. The virtual water concept encompasses a number of elements, phenomena, processes, and actors that are not usually associated with the water discourse. One could argue that when looking at the actors involved in the formulation and implementation of a virtual water trade policy, for instance, that it fits neatly into Political Science or Sociology. Bringing the transnational nature of virtual water trade into the equation it is totally compatible with the disciplines of International Relations and Development Studies.

The concept of virtual water is therefore at home within a number of scholarly disciplines. It is within this context that this paper will look at virtual water and the trade therein from an International Relations and Political Science perspective. This is not to say that these disciplines will be the only two that will present us with a clear picture of the elements involved. However, looking at virtual water from these disciplines will provide information about who and what is involved, and how these aspects influence each other concerning virtual water and the trade therein.

Geographically, the paper will focus on the Southern African Development Community (SADC). SADC consists of 14 member states; Angola, Botswana, Democratic Republic of Congo (DRC), Lesotho, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe. Temporally, the paper will concentrate on the current food security situation within the SADC region. Within SADC, the food security situation is driven by a number of environmental, political, and economic risks and opportunities. The research question to be answered will be as follows, namely: what are currently the main environmental, political, and economical conditions that are aggravating the food security situation within the SADC region?

To answer this question, the paper is divided into five parts. The first part of the paper takes a look at the current food security situation in SADC. In the second, the concept of virtual water and the benefits of a virtual water strategy is discussed. In the third section of the paper, the environmental, political, and economic risks and opportunities that influence a virtual water trade strategy are outlined. These conditions are either conducive or hindrances to such a strategy. A bird's-eye-view will be given of these risks and/or opportunities. Lastly, a conclusion is drawn, wherein the merits of a virtual water trade strategy in SADC are determined along the lines of the natural, political, and economic conditions prevailing in the region at the moment. The research question will also be answered in the conclusion.

2. Southern Africa in 2002: Food security or food insecurity?

2.1. Food Security and insecurity defined

The United Nations (UN) Food and Agriculture Organisation (FAO) defines "food insecurity as a situation where people live in fear of hunger and starvation". "Food security, on the other hand, exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (Turton *et al.*, 2000; FAO, 2002a; FAO, 2002b). Food security therefore consists of a number of components, namely:

- food should be available;

- people should have access to sufficient food;
- food supplies, at the individual, household, national, and regional level should be stable; and
- food should be of good and reliable quality (Barnett & Whiteside, 2002:238).

The definitions of food insecurity and security outline the conditions subsisting when one of these situations occurs within a country or region. With food insecurity there is a high probability that people will go hungry or face starvation, when they do not have access to adequate food supplies. There is therefore an inherent risk of dying of hunger or starvation when food insecurity is prevalent. Images of starving people also undermine the region's ability to attract foreign direct investment (FDI). These images are serious issues with complex ramifications. Regarding this, SADC member states are not only poor because of scarce water resources, but also because potential investors are scarred off because the economy of many countries remains stagnant. Food security, on the other hand, deals with the ways and means by which people obtain food to prevent the risk of death from hunger or starvation. These definitions will indicate the current food insecurity or security situation within some of the countries in SADC and the region as a whole.

2.2. Warnings of food insecurity

On 19 February 2002 a Special Alert was circulated by the FAO. The Alert warned that the food supply situation in Southern Africa is "tight". This was the result of a sharp fall in the 2001 cereal harvest. The Special Alert came after the UN had warned, in March 2001, that food shortages might occur within SADC. The Special Alert stated that the aggregate output of maize, the main staple in the region, is estimated at 13.4 million tonnes. This is one-quarter lower than in 2000 and below the average of the past five years (FAO, 2002c).

What also rose concern, regarding the Special Alert, was that the price of maize had increased several folds in a number of SADC countries a few months before the Alert. This subsequently undermined the access to food for large portions of the population in several countries, most notably, Malawi, Zambia and Zimbabwe (FAO, 2002c). In May 2002 the SADC Early Warning Unit said that the region faces a net maize deficit of between 3.22 million tonnes and 3.67 million tonnes (The Herald, 23 May 2002). Many people in SADC were therefore facing food insecurity.

2.3. SADC countries facing or experiencing food insecurity

The countries worst affected by the current crisis are Zambia, Zimbabwe and Malawi, though Mozambique, Swaziland, and Lesotho also face severe problems. Access to food for large sections of their populations has been severely undermined (*RTP Internacional Television*, 6 July 2002). Yet, the FAO stated that, world-wide some 34 countries are experiencing severe food shortages as of May 2002. Most of these countries are SADC members. Only Botswana, Lesotho, Mauritius, Namibia, Seychelles, and South Africa are not, to a large extent, facing this dire predicament. (FAO, 2002d).

Currently, large parts of the SADC region are indeed facing the predicted shortages of food (Meissner, 2002:99), with not only people in Malawi, Zambia, and Zimbabwe being vulnerable to food insecurity (The Herald, 23 May 2002).

The precarious food insecurity situation means that about 13 million people (22% of the region's population) are regionally experiencing serious food insecurity. This does not include the four million people already facing starvation because many countries had already depleted their maize reserves by May 2002 (The Herald, 23 May 2002; SAPA, 7 June 2002). In July 2002 it was reported, by the Lisbon based *RTP Internacional Television* (6 July 2002) that the SADC region is facing the worst food crisis since the Mozambican floods of 1992. By looking at the situation in the individual SADC states will give a clearer picture of the nature of food insecurity in those countries.

Angola

An FAO/World Food Programme (WFP) and Food Supply Assessment Mission visited Angola from 15 May to 6 June 2002. The purpose was to estimate crop production in 2002 and cereal import requirements in the 2002/03 marketing year (April/March). This mission found that about 1.4 million people were in urgent need of food assistance. Cereal import requirements for 2002/03 were estimated at 725 000 tonnes. Of this total 504 000 tonnes were expected to be commercial imports and 221 000 tonnes as emergency food aid (FAO, 2002e).

Lesotho

Lesotho has gone so far as to declare a state of famine. This is for a country that relies totally on food imports on an annual basis. At the same time, Lesotho continues to export R200 million of water per year, in a non-virtual sense, to South Africa through the Lesotho Highlands Water Project (LHWP) (Turton *et al.*, 2000; Meissner, 2002:100). In May 2002, Lesotho's Prime Minister Pakalitha Mosisili, told the press that the food insecurity situation "… is a massive problem for us and it will set us back [socio-economically], definitely" (Sunday Times, 19 May 2002:13). During the same time, a Special Report from the FAO and WFP noted that the domestic cereal supply in 2002/03 was estimated at 74 000 tonnes. This was at a time when the total national consumption requirement was estimated at 412 000 tonnes. This means that 338 000 tonnes had to be imported. Of Lesotho's total population of 1.9 million people, about 445 000 or 20% of the population were estimated to be food insecure by mid-2002 (Hirji & Molapo, 2002:8-9; *Beeld*, 27 June 2002:15; FAO, 2002f).

Malawi

In Malawi maize production dropped by over 33% in 2001. The strategic grain reserves had been exhausted and maize imports were constrained by transport bottlenecks. As a result, maize prices in some areas had increased by more than 300% since July 2001. In the four months up to March 2002, 500 people had already died of starvation (The Star, 7 May 2002:6). In February 2002, a woman from the central district of Kasungu asked journalists if they were willing to buy her five children to secure money for food. Murders increased in some parts of the country due to theft of food (The Star, 28 February 2002:4). The food insecurity situation in Malawi, in September 2002, was so severe that the WFP had scaled up food distribution to 2 million people. By December 2002, it was estimated that the WFP will have to feed 3.2 million people, representing 28% of the population. This will require about 30 000 tonnes of maize per month (*Beeld*, 27 June 2002:15; Business Day, 16 October 2002:4). A Special Report by the FAO and WFP stated, in May 2002, that the cereal supply in the 2002/03 marketing year "is estimated at 1.721 million tonnes. The national cereal requirement, on the other hand, is estimated at 2.206 million tonnes. This results in an import requirement of 485 000 tonnes" (FAO, 2002g).

Mozambique

The number of people receiving food assistance in Mozambique has increased from 100 000 in January 2002 to 190 000 in March 2002 (SAPA, 26 March 2002; *RTP Internacional Television*, 22 August 2002). In the same month, the Italian Government earmarked US$1.75 million for a food security programme, aimed at the rural poor. The programme's purpose was to equip rural communities with technologies that will ensure their food security, and covered areas like irrigation, livestock, and technologies for a rural environment (Radio Mozambique, 21 March 2002). In July 2002, about 600 000 people were already going hungry due to a lack of food in certain areas in Mozambique. This was especially the case in the southern, central and western provinces of Gaza, Inhambane and Tete where people were facing food insecurity (*RTP Internacional Television*, 9 July 2002). Notwithstanding this, national maize production was eight per cent higher than the previous year. However, this reflected an increase of 27% in the north and 13% in the central regions, while in the southern parts of the country there was a 38% decrease in maize production. Yet, it is estimated by the FAO that Mozambique will produce an exportable surplus of about 100 000 tonnes of maize in 2003. Nonetheless, due to high transport costs, surpluses available in the northern regions are not easily accessible to the southern parts of the country. They are instead exported to Malawi and other neighbouring countries. The southern and some of the central areas, on the other hand, will be covered by food aid and commercial imports (FAO, 2002h).

Namibia

At the end of August 2002 Namibia's prime minister, Hage Geingob, announced that food aid will also be distributed countrywide. In the Caprivi region all 79 000 inhabitants had registered for food aid (New Era, 4 August 2002:1). The situation in Namibia is therefore not so bad as in Malawi and even Swaziland.

Swaziland

Swaziland has send out a plea for help to the international community in March 2002 for food aid, as tens of thousands of Swazis faced food insecurity. The National Disaster Task Force (NDTF) told Swaziland's parliament that the number of communities in danger of starvation has increased from 47% to 80%. This was especially in the lowveld region where there were no harvests during the last season. Food shortages were affecting about 144 000 people out of a total population of one million (The Star, 20 March 2002:5), in other words, 14.4% of the population. As in Malawi and Zambia, people have resorted to eating wild fruit and berries to augment their diet (*Burger*, 17 April 2002:5). According to the FAO and WFP, in May 2002, the domestic cereal supply in 2002/03 was 77 000 tonnes, while the national consumption was estimated at 188 000 tonnes. There was therefore a deficit of 111 200 tonnes that had to be imported. Commercial imports were estimated at 96 000 tonnes and food aid at 15 200 tonnes that had to be covered by the Government and international assistance (FAO, 2002i).

Zambia

President Levy Mwanawasa of Zambia declared a national disaster in the Southern Province in May 2002. In a radio address to the nation he said that Zambians should refrain from exporting maize or other products. He also cautioned people living in rural areas not to sell all their food crops, but to save some for the future. The president said that production levels of maize, at the end of the season in June/July, will only cater for the needs of six million people out of a total population of 10 million. This meant that about four million are facing the risk of food insecurity (ZNBC, 30 May 2002). In November 2002, the media reported that people in the southern parts of Zambia had resorted to eating wild fruits, leaves and tree roots, some of which are poisonous. Not even pets were spared (The Star, 8 November 2002:6). In June 2002, the FAO estimated that the 2002 maize output will be about 606 000 tonnes, 24% below the poor harvest of 2001, and 42% lower than the normal crop of 2000. The cereal imports for 2002/03 were estimated at 626 000 tonnes (FAO, 2002j).

Zimbabwe

In Zimbabwe, the situation is even more dire where maize production in 2001 fell by 28%. Production is estimated to be only 400 000 tonnes, or 20% of demand and by mid-January 2002 the Grain Marketing Board had run out of stock. The drastic reduction in production was caused mainly by political upheaval, reduced plantings, dry spells and excessive precipitation. Strategic maize stocks are also depleted. Zimbabwe, along with South Africa, was once one of Southern Africa's 'bread baskets' but has now fallen on hard times. In May 2002, the government declared some areas, disaster zones where 7.8 million people (5.4 million of them children) are in need of food aid (Meissner, 2002:100). This represents 46% of the total population of Zimbabwe (*Beeld*, 27 June 2002:15). In the same month, an FAO and WFP mission concluded that the country is facing a serious food crisis. International food assistance was urgently and adequately needed to avoid a serious famine and loss of life. The production of maize was estimated to be only 0.48 million tonnes, a decrease of 67% on the 2001 harvest and 77% lower than the 1999/2000 harvest. Import requirements for cereals for 2002/03 were estimated at an alarming 1.869 million tonnes, of which maize accounted for 1.705 million tonnes, or 91% (FAO, 2002k). In December 2002 it was reported that families have access to food only once a week because they do not have the financial resources to buy food. This, when rural food production has already collapsed. It is even forecasted by the UN that Zimbabwe will be a 'failed' state by the end of February 2003. This will worsen an already precarious food insecurity situation (SABC, 7 December 2002), because of a failure of the institutional apparatus of the state.

The situation is expected to worsen during the next few months in most of the states already mentioned because of projected falls in production in the early part of 2002. The current food security situation in Southern Africa is exemplified by the volume of cereal imports and food aid requirements. According to the FAO, in 2001 the region produced 19.2 million tonnes of maize. Currently it is expected that an additional 3.9 million tonnes will be needed. It is furthermore anticipated that 3.5 million tonnes will be commercially imported (Meissner, 2002:100). Where will the food come from?

2.4. South Africa's uncertain maize crop

In contrast to the gloom above, prospects for the 2002 maize crop in South Africa are favourable. Production is also expected to recover from last year's below-average level. This was unfortunately the situation in May 2002. Much has changed since then. South Africa is currently also facing a shortage of some 4 million tonnes of maize, while it needs about 8 million tonnes per annum, if it does not rain soon. Because of this foreseeable shortfall, the prices of all maize products are expected to increase from the beginning of 2003. Currently a tonne of maize is trading for around R1 650 or US$200. It is not only maize that is expected to be in short supply. The supply of sunflower, soy beans, and peanuts is also expected to drop. Because of this, it is envisaged that South Africa will not be able to export any maize to its northern neighbours during the current season and will most probably have to import maize itself. South Africa, in terms of maize production and exports, is considered the bread basket of the SADC region (this is reflected in comparable irrigated agricultural area of the SADC member states (see Table 1 below)). According to Bully Bothma, Chair of the Grain Institute of South Africa, maize is also in short supply on the global maize market (SABC, 2 December 2002). This is an ill prognosis for the entire region. Food prices on the international cereal market could rise this coming season. This will make it more difficult for cash strapped economies to buy food stuffs, like maize.

What might off-set the shortage of maize in South Africa, is that more farmers might plant maize, instead of vegetables, this season on irrigated land. The reason for this is the high maize price. Because of this, a bumper crop of about 8.1 million tonnes of maize, is forecasted for the coming season. On top of this, soil moisture conservation techniques practised by farmers has had the effect that there is adequate moisture for the planting of maize in some areas. Yet, caution should not be thrown to the wind, and in December it was too early to say what the maize harvest in South Africa would be. The future maize harvest would also depend on rainfall during February and March. This is a critical time for maize plants, for they are in a vulnerable stage of development, and need adequate water to secure their survival (*Rapport*, 3 November 2002:22).

Some parts of South Africa, especially the maize producing areas did receive some rain at the beginning of December. Certain areas in the Northwest and Free State Provinces received between three to 40 millimetres (mm) of rain. This was good news for some farmers, but others have not yet received adequate rain to start planting. Yet, South Africa has not entered a drought situation. There are, however, danger signs. For instance, parts of the Free State, Gauteng, and Mpumalanga provinces have not yet received average or above average rain (RSG, 5 December 2002). Rain is therefore the all-important factor that influences the planting of maize and other crops. Irrigation is a measure that might have a positive influence on the volume of maize to be planted, but it is not as important as rain.

Table 1. Irrigated agricultural area (thousand hectares) in SADC Member States.

Country	1961	1965	1970	1975	1980	1985	1990	1995	2000
Angola	75	75	75	75	75	75	75	75	75
Botswana	1	2	1	1	2	2	2	1	1
DRC	-	-	-	-	7	9	10	11	11
Lesotho	1	1	1	1	1	1	1	1	1
Malawi	1	1	4	13	18	18	20	28	28
Mauritius	8	12	15	15	16	17	17	18	20
Mozambique	8	16	26	40	65	93	105	107	107
Namibia	4	4	4	4	4	4	4	7	7
South Africa	*808*	*890*	*1000*	*1017*	*1128*	*1128*	*1290*	*1300*	*1498*
Swaziland	36	40	47	56	58	62	67	69	70
Tanzania	20	28	38	52	120	127	144	150	160
Zambia	2	2	9	18	19	28	30	46	46
Zimbabwe	22	34	46	70	80	90	100	117	117
SADC Total	*986*	*1105*	*1266*	*1362*	*1593*	*1654*	*1865*	*1930*	*2141*

Source: FAO (2002l).

Furthermore, the irrigated area in South Africa, represents only a fraction of the area that is arable and planted with permanent crops. In 2000, South African farmers irrigated a total area of 1.498 million hectares (ha). Notwithstanding this, the total area of arable land and planted with permanent crops is an estimated 15.712 million ha (FAO, 2002m). Therefore, irrigated land represents less than 10% of the agricultural productive land in South Africa, and therefore many farmers, both commercial and subsistence, rely on rainfall for the production of food stuffs.

Table 2. Southern Africa in 2002: Food security or food insecurity?. Food security or insecurity in the SADC region in 2002, based on food requirements (cereals) for the coming (2002/03) season, based on FAO and WFP data.

Country	Maize Required (in tonnes)	Food Security?	Food Insecurity?
Angola	725 000	No	Yes
Botswana	No data available	Yes	No
DRC	No data available	-	-
Lesotho	338 000	No	Yes
Malawi	2.206 million	No	Yes
Mauritius	No data available	-	-
Mozambique	Surplus of 100 000 tonnes of maize in northern region	Yes (Northern regions)	Yes (Southern and central areas)
Namibia	No data available, but some food aid required.	Yes	No
Seychelles	No data available	-	-
South Africa	Possible surplus of 100 000 tonnes (maize) in coming season	Yes	No
Swaziland	111 200	No	Yes
Tanzania	No data available	-	-
Zambia	626 000	No	Yes
Zimbabwe	1.869 million	No	Yes

In summary, many SADC member states are facing a situation of food insecurity or are already experiencing it. These states are Angola, Lesotho, Malawi, parts of Mozambique, Swaziland, Zambia, and Zimbabwe. The dire food insecurity situation may be mitigated by international and regional assistance but the underlying natural, political, and economic conditions need to be looked at and where possible remedied (Meissner, 2002:99). The notion of virtual water may contain some of these remedies. Furthermore, given the current food insecurity situation in the majority of SADC countries at the moment, it seems as if a virtual water trade strategy is therefore required.

3. Virtual water

Given the great propensity of food insecurity in the region, it becomes plain that some attempt should be made to look beyond the current crisis and reduce the risk that this will be repeated. Since water plays a central role in crop production, it is advisable to consider how much water is needed to produce the food a region or country requires (Dimitrov, 2002:682).

Virtual water refers to this volume of water required to produce a certain commodity or service (Allan, 2002:29). Maize, for example, requires about 900 tonnes of water to produce one tonne of the staple. When a state imports a tonne of maize it is effectively importing 900 tonnes of water.

In international and regional economies vast quantities of virtual water are present. For instance, it takes about 1 000 tonnes (cubic metres) of water to grow one tonne of grain. This is the virtual water value of grain. Similarly, to produce one tonne of rice, 2 000 tonnes of water are needed; one tonne of wheat needs 1 000 tonnes of water. Because virtual water is embedded in the international political economy, every state in the international political system is subjected to trade in virtual water (Allan, 1999:29; Turton *et al*., 2000; Allan; 2002:29). This is evident in the cereal needs of many SADC countries at present. What exactly are the political and economical benefits of a virtual water trade strategy, seen in the light that it can mitigate food insecurity and water deficits?

Firstly, hydropolitical crises in a region or country, associated with water deficits, are to be avoided by a virtual water strategy. This is the case for SADC economies. Secondly, political decision-makers struggling with water deficits in semi-arid regions and countries are the main winners. Virtual water is the ultimate solution in regions and countries with water-stressed economies. According to Allan (2002:29): "[I]t provides an extremely effective operational solution with no apparent downside. Virtual water is economically invisible and politically silent. Those politicians struggling with challenging politics welcome solutions that are economically invisible. They especially welcome those that are politically silent and devoid of political costs".

Almost all countries have to trade in foodstuffs because they cannot produce all their food locally. This is especially true of developing states. Virtual water is therefore an important aspect of a country's food security. This infers that as countries trade in agricultural commodities, they are also importing and exporting water in a virtual sense. Intra-regional trade in food is, furthermore, an important aspect of regional trade within the SADC region. For instance, at the end of 2001, South Africa exported about 9 000 tonnes of maize to Zimbabwe. In a virtual water sense, South Africa exported about 8.1 million tonnes of water (Meissner, 2002:101).

In theory, when a region does not have enough water to supply its food needs, it will turn to the international market to augment supplies. The truth is that this is more complex and often more difficult than it seems. The reasons for this are environmental, political, and economical in nature.

4. Environmental factors

4.1. El Niño

Weather is one of the most important variables that determines the success or failure of a harvest. Extreme weather, particularly excessive rain (resulting in floods) and abnormally low rainfall (resulting in drought) was named as some of the causes of the wide-spread food insecurity in SADC. For instance, the rains in Mozambique and Malawi were too late to save crops that were badly damaged by drought in January 2002. This was on top of the devastating floods that occurred in Mozambique during the rainy seasons of 2000 and 2001. About 22 000 ha of land in Mozambique were ruined (*SAPA*, 26 March 2002; RSG, 5 December 2002). Floods in 2001 were therefore the initial cause of food shortages in Mozambique and Malawi. Yet, drought is at present the main culprit responsible for the food insecurity in many parts of SADC. The drought is mainly caused by the El Niño-Southern Oscillation (ENSO) phenomenon. (In this paper the term 'El Niño' will be used when referring to this weather occurrence).

El Niño is an unusual warm ocean current along the west coast of South America. The name refers to the Christ child because the event turns up at around Christmas. Cold nutrient rich ocean surface waters are replaced by warm nutrient poor ocean waters. El Niño has a severe impact on global weather patterns, causing drought in some regions and floods in other parts of the world (Meissner, 2001).

It is forecasted that the present drought will be the worst in 50 years, if it does not rain soon over the region. A region-wide drought is an environmental phenomenon, threatening regional food security because water shortages diminish food production. Weather forecasts at the beginning of 2002 suggested that in 2002/03 the El Niño occurrence may make its appearance in the Pacific Ocean off the western coast of Latin America. With these forecasts came the spectre of a regional drought in Southern Africa (*Rapport*, 7 April 2002:8; *Volksblad*, 7 May 2002:1; Dimitrov, 2002:683). In South Africa, 50% below normal rainfall was forecasted for the period November to January (*Rapport*, 3 November 2002:22). What are the likely impacts of an El Niño-induced drought on the economies of the SADC region? South Africa will be taken as the yardstick. The reason for this is that it is the economic power house in the region and will give an indication of what is to be expected in other SADC member states.

Firstly, it will negatively influence food supplies and demands, because food prices will increase substantially. The International Monetary Fund (IMF) states that and El Niño-induced drought, during any season, will increase commodity price inflation with about 20% and consumer price inflation with nearly 10%. Secondly, it will result in job losses, especially in the rural areas where commercial agriculture is the main economic activity. This will negatively influence the spending patterns of people in rural towns. Thirdly, for agricultural production it will mean a loss of between 10% and 20% because of poor harvests and pasturage. This means that agricultural income for South Africa might drop by R8 billion, resulting in a one per cent lower economic growth rate. In the 1995/96 season it was calculated that the maize crop was R2.1 billion lower than the previous season's, because of El Niño. In the fourth place, the price of water for the agricultural and industrial sectors will increase substantially, if an El Niño-induced drought becomes a crisis. Both these sectors together use 90% of South Africa's water resources. This might result in an increase in industrial goods that could also negatively affect the inflation and economic growth rate (*Finansies & Tegniek*, 26 April 2002:46).

The reports regarding El Niño seem to be correct. Southern Africa is at present experiencing a drought while there is uncertainty regarding the coming seasonable rains in South Africa. Another environmental threat, with probable negative socio-economic consequences, is the human immunodeficiency virus (HIV), which causes acquired immunodeficiency syndrome (AIDS).

4.2. HIV/AIDS

The current food insecurity situation within the SADC region is also compounded by the extensive malnutrition of disease affected populations; diseases like malaria, cholera, tuberculoses, and particularly HIV/AIDS (The Herald, 23 May 2002). The reason for including HIV/AIDS under environmental threats, is that the risk emanates from a single-cell organism, HIV, that causes AIDS (Ashton & Ramasar, 2002:217).

At this moment Southern Africa is not only suffering from a severe drought, but the region's HIV/AIDS pandemic is the worst in the world. The pandemic is being compounded by food insecurity in the region. Those individuals living with HIV/AIDS are especially vulnerable in such a situation (Namibia Economist, 22 November - 28 November 2002:4). Their nutritional intake per day is well below standards that makes them more susceptible for AIDS related diseases like tuberculoses. Furthermore, and taking Zimbabwe as an example, because of the drought in that country, people, especially women, without money to buy food has resorted to prostitution for an income. In a situation like this (where 2 500 people die of AIDS in Zimbabwe per week) the spread of HIV/AIDS only worsens (SABC, 7 December 2002). It is therefore important to prevent the spread of the disease.

The importance of preventing the spread of HIV/AIDS is reflected in the African Development Bank's (ADB) theme of 'AIDS, Conflict and Food Security' on World AIDS Day (1 December 2002). The Bank notes that these issues are the greatest stumbling-blocks in Africa's future socio-economic development (ADB, 29 November 2002). Clearly the ADB is very concerned about the spread of the pandemic, coupled with food security and armed conflict on the African continent. Nonetheless, what is some of the effects of HIV/AIDS on a country's agricultural sector, especially those with a mainly agrarian economy, like Malawi?

Firstly, HIV/AIDS has a negative impact on the agricultural workforce. In the ten most infected countries in Africa, decreases in the labour force from 10% to 26% are anticipated by the FAO. Seven of these are SADC member states. They are as follows, namely (with their projected losses of agricultural labour force in percentages in 2020): Namibia (26), Botswana (23.2), Zimbabwe (22.7), Mozambique (20), South Africa (19.9), Malawi (13.8), and Tanzania (12.7). Seven million agricultural workers have already died from AIDS since 1985 (FAO, 2002n; Fourie & Schönteich, 2002:18), impacting severely on food security.

Secondly, HIV/AIDS has an impact on food production, through sickness and death in that fields cannot be tended and animal husbandry and livestock production decline. Thirdly, it affects the commercial production of foodstuffs. On small farms cash and subsistence crops cannot be produced because of a labour shortage (FAO, 2002n). In this case, HIV/AIDS has an impact on food security by reducing a household or country's ability to keep up a diverse portfolio of activities and to produce and buy food (Barnett & Whiteside, 2002:239). For instance, in 1999, the Zimbabwean Commercial Farmers' Union produced figures that reflected upon the decline of the country's food output. It stated that maize production had dropped by 60%, cotton by 47% and vegetables by 49%. The reason given for this decline was HIV/AIDS (Mail & Guardian, 16 August 1999:4; Fourie & Schönteich, 2002:17). In the fourth place, HIV/AIDS has a negative impact on household wealth. In other words, HIV/AIDS aggravate poverty on the household level. So-called AIDS orphans is usually taken in by relatives or members of their community. This puts a further economic burden on already poor households. If household poverty increases, then so too does household food insecurity.

HIV/AIDS' impact on the food security situation of a region may not be as immediate as that of an El Niño-induced drought. However, looking at some of the impacts of the pandemic on food security will indicate what might happen in future. Furthermore, El Niño-induced droughts and HIV/AIDS are not the only issues to be considered when contemplating a virtual water trade strategy. Political factors, and especially political conditions and decisions, are also important in this respect. These factors will highlight the political processes that will either check or expedite a virtual water trade strategy.

5. Political conditions and decisions

Unstable political conditions and political decisions will either worsen or improve a food insecurity situation. For instance, the food crisis in Zimbabwe is mainly attributed to the actions of the ZANU-PF government and particularly the controversial land reform policies (Meissner, 2002:101). For the past two years the Zimbabwean government has been implementing this policy. The government seized land from large-scale white commercial farmers, in an attempt to redistribute it to landless black families (The Financial Gazette, 25 April 2002).

The land reform policy is also implemented in conjunction with a resettlement mechanisation programme to enhance newly resettled farmer's ability to safeguard the country's food security. This policy is seen by the political leadership of Zimbabwe as a comprehensive approach to food security. One of the aspects of the mechanisation programme is the improvement of food production through irrigation. Under the programme, rural and commercial farming areas will be reorganised. Efforts will be made to secure irrigation equipment, water pumps, sprinklers, grading machines to position the farmer into full-scale agricultural production. Zimbabwe's Minister of Lands, Agriculture and Rural Resettlement, Cde Joseph Made, said that the government has irrigation pumps and other equipment for farmers to hire to boost agricultural production (The Herald, 22 April 2002).

What is also significant regarding the Zimbabwean land reform policy, from a water resources management perspective, is that the government has declared all land developed for irrigation as strategic. Made stated in July 2002, that irrigatable land will be given priority to improve food security and create employment. He said that: "In the past some irrigatable land was left for grazing when it could be used for maximum agricultural production. That is no longer acceptable". Together with this announcement, the government also said that financial resources will become available to ensure that all irrigatable land in the country is fully used by farmers (The Herald, 1 July 2002). A reason for this announcement by the Zimbabwean government is that it started to feel the pinch of the drought and the subsequent food insecurity situation. It therefore had to come up with a coping strategy, in the traditional sense of mobilising more water resources, to increase food production to ameliorate the situation.

Be that as it may, the Zimbabwean land reform policy is a controversial one. Not only has it led to political instability in some parts of the country. It has also invoked a critical response from the international community, especially the Commonwealth, with Great Britain and Australia leading the way. In terms of internal political conditions, the decision of the government to embark on this policy has led to human rights violations. Farmers had been evicted from their farms without compensation and virtually within a few hours. What is significant, concerning food security, was that farmers were prohibited, by law, to harvest their crops. Under such conditions, together with the drought at present, the food security situation was bound to deteriorate. Reports from Zimbabwe also state that people, who are not ZANU-PF supporters, are not getting any food aid. Only if a person has proof that he or she supports the ruling party are they able to get food. This has been denied by the ZANU-PF, but people in Zimbabwe in need of food aid have verified the reports (SABC, 7 December 2002). While the Zimbabwean agricultural sector was reeling under a controversial land reform policy, other SADC member states were making great strides towards political stability where there was previously none a year ago.

Angolan society has been ravaged by civil war for 27 years (1975-2002). On 22 February 2002 Jonas Savimbi, leader of the rebel movement, the Union for the Total Independence of Angola (UNITA), was killed in battle. Savimbi played a major role in the continuation of the Angolan civil war. This, after his refusal to accept the general election results in 1994, that secured the rule of the Popular Movement for the Liberation of Angola (MPLA). The death of Savimbi, and 18 days later of UNITA Gen. Antonio Dembo, signalled the end of the civil war in Angola (Natal Witness, 25 February 2002:8). On 25 February the Angolan President, José Eduardo dos Santos, called a cease-fire in Africa's longest civil war (The Star, 26 February 2002:4).

Six weeks later (4 April 2002) the cease-fire agreement was signed between the Angolan Armed Forces (FAA) and UNITA in Luanda. With the signing of the agreement Dos Santos announced that "the war is over and peace has come back for good" (Cape Argus, 5 April 2002:5; Porto & Clover, 2002:1). It is not sure whether this will be a lasting peace, for Angolan society has been oscillating between war and peace for the last decade.

Yet, things are looking bright for Angola's future, within the context of socio-economic development, especially with one of the main antagonists out of the way (Naidoo, 2002:27).

Angola could become one of the richest country's on the African continent, due to its natural resource base. However, Angolan society has known nothing but war and conflict. More people have died because of malnutrition, disease and a lack of potable water and sanitation, than during the war itself (Clover, 2002:103). Angola is therefore a country that is on the verge of getting out of its war torn past and entering a period of lasting stability and the upliftment of its population.

It is because of the great necessity for socio-economic development, coupled with sustained political stability, that the UN has appealed for US$384 million for humanitarian and development operations in Angola in November 2002. Lise Grand, of the UN Office for the Co-ordination of Humanitarian Affairs (OCHA) in Luanda, said that: "We want to access populations in acute distress, and we want to stabilise them. We want to support the return and resettlement of IDPs [internally displaced persons] on the basis of the government's legal code and we want to promote self-sufficiency through agricultural revitalisation" (Namibian Economist, 22 November - 28 November 2002:21). Since 1998 about four million people were displaced from their homes. Yet, since the end of the civil war about two million have been allocated land and are no longer dependent on food assistance (FAO, 2002d). This is a great leap forward in the fight against food insecurity. Furthermore and because of Angola's run-down economy, it is expected that agriculture will play a major role in its revitalisation. In future, the country might even become one of SADC's bread baskets.

Angola has escaped the ravages of the drought that is affecting the rest of the SADC region. However, since the cease-fire agreement, the extent of the suffering of the people in the rural areas has been revealed. According to an FAO and WFP mission to Angola in July 2002, large numbers of malnourished people have since April made their way to reception and transit centres. Up to 500 000 people are reported to be in a critical nutritional situation (FAO, 2002d). The Angolan civil war has therefore had a significant and adverse impact on the food security situation of its population. It was also the greatest obstacle to Angola becoming a food self-sufficient country and even a major player in a region-wide virtual water trade strategy.

Conflicts have mainly political causes and need to be addressed within political forums, like the ending of the Angolan civil war. In a situation like this, a virtual water trade strategy is only possible after sustainable peace has been secured. Land reforms in Zimbabwe and the end of the Angolan civil war, are presently major political events in SADC. Notwithstanding these immense occurrences, what other political phenomena are either exacerbating or mitigating a food insecurity situation?

One of the causes of Malawi's food insecurity situation has been laid at the door of the IMF and the World Bank. Four years ago, the government distributed agricultural starter packs, including fertiliser, to 2.8 million subsistence farmers. This policy assured a bumper maize harvest in 1999 and 2000. Nonetheless, the beneficiaries were scaled down to one million after reduced sponsorship and pressure to abolish subsidies. This was in line with agricultural reforms advocated by international financial institutions like the IMF and World Bank. What deepened the present food crisis, was that Malawi sold off its strategic grain reserves. This was despite warnings that the harvest was likely to be poor. Nearly 27 000 tonnes of maize was exported at a loss (Business Day, 16 October 2002:4).

In this case, outer peripheral (from outside the region) actors on the international stage have therefore either had a direct or indirect impact on the country's food security situation. These actors are tangible, and their pressure for reforms on a country like Malawi is also tangible. What about those non-tangible issues, like discourses[1] that will influence actors to behave in a certain way? Zambia, and its recent decision not to accept genetically modified food (GMF) to alleviate food insecurity for some of its population, is an example.

Zambia has banned the distribution of all GMF from the United States in August 2002. This was despite the huge shortages of food in the country. The main reason for the rejection of GMF was health concerns (New Era, 22 August 2002:6; The Star, 22 August 2002:13; Business Day, 16 October 2002:4). The Zambian Information Minister, Newstead Zimba, said that government took the precaution: "[I]n light of uncertainties surrounding the likely consequences of consuming genetically modified food…". The United States, on the other hand, said that it's genetically modified (GM) maize is safe. Several food experts also urged Zambia to accept it. Zambia rebutted by stating that the GM maize poses a long-term risk to its food security, because

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[1] According to Michel Foucault, discourses are systems of talking about things which has consequences for power (Haralambos & Holborn, 2000:635).

there is the risk that it might be toxic and could corrupt local seed. This was after the United States offered to give Zambia 23 000 tonnes of GM maize. If Zambia had accepted the offer, some 28 000 tonnes more would have been donated (New Era, 22 August 2002:6).

The Zambian government had arranged to import 300 000 tonnes of non-modified maize for immediate food needs in August 2002. A further 156 000 tonnes would have also been bought and placed in a strategic reserve to be used when necessary (New Era, 22 August 2002:6). By mid-September it was revealed that Zambia had only three weeks' worth of non-GM maize to feed almost three million people. Regarding the non-safety of GM maize, Zambia sent a team of scientists to South Africa and Europe to research the safety of GM maize, and after the findings to review its policy on GMF. Four other SADC countries took a different policy route and accepted GM maize - Mozambique, Malawi, Zimbabwe, and Lesotho, on condition that the seeds are milled into flour. This was to ensure that no seeds enter the environment (Business Day, 17 September 2002:5; Mail & Guardian, 1 November 2002). It seems as if Zambia is on the verge of creating a precedent in the developing world, regarding the issue of GMF?

The scientific team reported back to government at the beginning of November. The results of the report were not published. Yet, one of its authors Dr. Mwananyanda Lewanika, said that the team was impressed by Norway's hostile stance towards GMF. This was not the case with South Africa that had already started to commercially plant GM maize. Zambia went one step further than the other four countries that accepted GM maize. It even banned milled GM maize (Mail & Guardian, 1 November 2002).

The refusal to use GM maize has resulted in the looting of warehouses where it was stored. The refusal to use GM maize was popular with the urban élite. They saw the issue as a test of 'national strength'. Villages, where food insecurity is a fact, who wanted the GM maize lacked the political power to exert influence over government to supply them with food. A Greenpeace spokesperson, Charlie Kronick said that Zambia's decision was a "triumph of national sovereignty. The US has been putting pressure on countries to accept GM surpluses produced by its farmers". Contrariwise, the WFP said that this decision will complicate its work, because it may not respond to everyone's food needs. Guy Scott, a former Zambian agricultural minister, said that the onus will rest with the interest groups who had approved of Zambia's decision not to accept GM maize. The reason for this is the risk of starvation and even death to which rural people had been exposed (Mail & Guardian, 1 November 2002).

Because of Zambia's decision, about 15 000 tonnes of GM maize will most likely be given to neighbouring countries (Mail & Guardian, 1 November 2002). They are probably Malawi and Zimbabwe, where the food insecurity situation is severe.

Although the Zambian government had made the decision, after scientific proof had been obtained, the discourse surrounding the health risks of GMF emanated from the global environmental movement. The political leadership of Zambia acted to avoid risks, but could, at the same time exasperated the risk of starvation of a large part of the rural population. Therefore, political leaders are risk avoiders (Allan, 2002:31), but they will also, and inadvertently so, create or exacerbate risks through their decisions. This is not only the case regarding GMF in Zambia. The Zimbabwean leadership, with its controversial land reform policy, has been one of the factors contributing to the country's food insecurity, putting large portions of its population at risk of starvation.

Politics, and water politics in particular, involves political processes and actors, that make decisions and who are influenced by national and international political conditions flowing from the actions and decisions of other actors. By looking at these aspects will only paint the picture of the current food insecurity situation in the region to a certain extent. What should also be considered are the economical factors prevalent in a society. These factors will dictate the level of second order resources (in terms of economic capacity), needed to get access to virtual water agricultural commodities from the regional or international food market.

6. Economic capacity

Economical factors, such as the availability of foreign exchange and capital outlay on infrastructure also play a role when governments consider a virtual water trade strategy. Where government finances are stretched to the limit by debt and mismanagement, countries will have difficulty implementing infrastructural projects to facilitate the distribution or production of food within a region.

In other words, the strength of a country's economy will mean the difference between food insecurity and food security. For instance, irrigation schemes cannot be financed that will lead to a better food security situation. In times of need, especially at this moment in SADC, countries will find it difficult to secure money to buy food on the international cereal market. A country with a currency that has lost much of its value will find it more difficult to import food, than a state with a strong currency *vis-à-vis* the US dollar. (Food imports are paid for in US dollars). This is the case with Lesotho, Malawi and Zimbabwe. The Zimbabwean dollar has lost much of its value over the past two years, as have happened with Malawi's *Kwacha* and Lesotho's *Maloti* (*Volksblad*, 7 May 2002:1).

Not only that, where people are earning very little their individual food security will also be compromised, for they lack the necessary means to get access to food.

A state's economic capacity regarding gross domestic product (GDP) and gross national income (GNI)[2], are indicators of its capacity to acquire food stuffs on the international cereal market. Gross domestic product asserts the total value of all goods and services produced within the borders of a state *per annum*. It is a good measure when investigating the level of economic activity in a state. The economic growth of a state shows the percentage decline or increase of its GDP. Gross national income, on the other hand, is a better indicator of the standard of living of the citizens of a country. The figures presented in Table 6.1 indicates the strength of the economies of the SADC countries. In this case, GNI *per capita* regarding purchasing power parity (PPP) (expressed in international US$), is used to determine a state's economic capacity. It therefore indicates a country's second order financial resources to safeguard it against food insecurity. Purchasing power parity is a method to gauge the relative cost of living in a particular state. This is done by ascertaining how many citizens have the ability to buy products and services in US$ terms in their home countries (Nel & McGowan, 1999:319, 327). This is important when considering the issues of food security and food insecurity, because PPP indicates the number of people that have access to food, through financial means.

Table 3. Gross National Income and ranking of the SADC member states.

Country	Ranking	GNI per capita (PPP) (International US Dollars)
Angola	181	1180
Botswana	84	7170
Democratic Republic of Congo	201	680
Lesotho	146	2590
Malawi	203	600
Mauritius	70	9940
Mozambique	193	800
Namibia	89	6410
Seychelles	65	-
South Africa	72	9160
Swaziland	112	4600
Tanzania	206	520
Zambia	198	750
Zimbabwe	148	2550

Source: The World Bank (2000).

From Table 3 a number of conclusions are drawn. Firstly, the countries worst hit by the current food insecurity situation are countries whose economies are ranked as some of the lowest in the world. Malawi is the second lowest ranked economy in the SADC region, followed by Zambia, Zimbabwe, Lesotho and Swaziland. In all five countries, reports of starvation, declining food reserves, and food aid from the international community has

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[2] 'Gross national income' (GNI) has replaced the previous term 'gross national product' (GDP).

been reported during 2002. These countries will therefore find it difficult to secure enough food stuffs on the international cereal market during the coming season because of their low economic capacity to buy food.

Secondly, Zimbabwe's economy is ranked 148th, compared to the DRC's 201st, Mozambique's 193rd, and Angola's 181st. However, Zimbabwe is in a dire food insecurity situation, while this is not the case in the other three countries, except in Mozambique's southern regions. The cost of food imports in Zimbabwe is also affected by a shortage of foreign exchange. This is an indication of the impact the controversial land reform policies, together with drought, have had on the agricultural sector and Zimbabwe's food security.

Thirdly, the stronger economies in the region Botswana, Namibia, and South Africa have a high level of food security. This is despite Namibia's appeal for food assistance, and the uncertainty surrounding the maize harvest in South Africa in the coming months. Thus, these countries have the economic capacity to weather the storm of a potential food insecurity situation threatening their populations. For instance, Botswana, with its relatively strong economy, compared to Malawi's, has since 1991 stopped to irrigate on a large scale. This is a direct consequence of the National Water Master Plan Study, completed in 1991. Because of the Study, Botswana abandoned its strategy of food self-sufficiency and adopted an alternative policy of economic development for food security. This allows Botswana to have a strong economy to buy food on the international cereal market (Ohlsson, 1995; Matiza Chiuta, Johnson, Hirji, 2002:34). Thus, Botswana has the economic capacity, through its diamond industry, tourism, and industrial sector, to afford a virtual water trade strategy. This results in a high level of food security for its population, a situation some of its northern neighbours can only envy. The same situation, regarding a strong economy, is found in South Africa. Yet, South Africa continues with a strategy of food self-sufficiency. This is because irrigated agriculture had been promoted and subsidised by successive National Party governments after the depression and severe drought of the 1930s.

Within the context of the economic capacity of countries, one of the most important solutions for water and food deficit economies is therefore socio-economic development. In the wake of socio-economic development follow adaptive capacity to deal with the challenges of water deficits and food shortages. (Such is the case with Botswana, Namibia, and South Africa). Regarding this, water and food scarcities have two orders. Firstly, first-order scarcities are the scarcity of the primary commodity, water and food. Second-order scarcities is the capacity of a country to adjust first-order scarcities. Examples of second-order resources are institutional capacity, financial resources, human resources, infrastructure, etc. First-order scarcities of water and food are not as important as second-order scarcities, located in the adaptive capacity to deal with such scarcities (Ohlsson, 1999; Turton & Ohlsson, 1999; Turton *et al.*, 2000; Allan, 2002:30).

Therefore, a region or country, facing a water or food deficit, will be able to ameliorate the deficit by the introduction of second-order economic, administrative, institutional, and infrastructural resources. Zimbabwe is a good example where these second-order resources are absent. Zimbabwe has the capacity to produce enough food for its population. This is evident in Zimbabwe's history as one of the bread baskets of the region. However, this is not the case anymore, for its land reform policy had depleted much of its second-order infrastructural resources, in that commercial farmers are not allowed to work their land (SABC, 7 December 2002). Therefore, through its land reform policy, Zimbabwe has "removed" much of its second-order resources. This makes it vulnerable to food scarcities, for it does not have the capacity to produce or import food.

Lesotho, on the other hand, is a country that exports R200 million of water, in a non-virtual sense to South Africa. At first glance, it would be presumed that the country has enough second-order resources to buy food from either South Africa or on the international cereal market. Yet, a study by Turton *et al.* (2000) on virtual water and water scarcity in Southern Africa found that the country's economic base is too weak to pay for virtual water imports.

This implies that socio-economic development in Lesotho and elsewhere in Southern Africa, as Allan (2002) asserts, seems to be the best strategic option in the long run regarding a virtual water trade strategy.

7. Conclusion

A large majority of SADC member states are either facing food insecurity or are experiencing such a situation. This is exemplified by the number of people who are dependent on food assistance or who are food insecure. In

July 2002 around 600 000 people were already going hungry in Mozambique. In Lesotho and Malawi about 1.9 million and 3.2 million people are food insecure respectively. Botswana, South Africa, and to a large extent Namibia, are not experiencing the same situation.

A situation where food insecurity is at the order of day is an opportunity that is conducive to a country or an entire region resorting to and implementing a virtual water trade strategy. The question that has to be looked at, is where will the food come from? South Africa is likely to export food to the rest of the region. However, there is uncertainty about South Africa's ability to produce enough food for its population in the coming season. If South Africa experience a drought during this season, it would itself have to resort to food imports from other parts of the world, most notably North America. Thus, the next best thing for large parts of SADC, if this scenario should realise, is to buy virtual water agricultural commodities on the international cereal market.

International virtual water commodities will therefore be the helping hand. Logically, many Southern African countries will be ill advised not to go this route, because of virtual water's economical and political benefits. Politicians will have an economically invisible and politically silent solution at their disposal to turn food insecurity into food security. Yet, a number of variables are playing havoc with such a policy at the moment.

Firstly, the El Niño-induced drought, that large part of the sub-continent is experiencing, has resulted in a situation where food is needed at this moment and not in the long run. This means that the first-order resource, water and consequently food, is scarce and is likely to become scarcer. It also highlights the connection between water, or the scarcity thereof, and food production; no water, no food.

Secondly, HIV/AIDS, with its negative socio-economic ramifications, is also a hindrance to a virtual water trade strategy, not only on a regional, but also a global scale. Less agricultural workers, a primary second-order resource in an agricultural economy, means less production of staple foods such as maize. Even subsistence farming is threatened by the pandemic. Subsistence farming plays an important role in the food security of mainly agrarian economies. People who do not have the economic capacity to obtain food through financial means rely heavily on this type of agriculture. In rural areas the number of AIDS orphans will most probably increase, while the burden will fall on already cash strapped household economies to care for them.

However, the HIV/AIDS pandemic could also free up much needed land as people are struck down by the disease and plots of land are vacated. This would be similar to Europe in the Middle Ages with the bubonic plague that killed thousands if not millions. The result of which was that more agricultural land became available, more intensive agricultural methods were introduced and thus began Europe's agricultural revolution. Nonetheless, the socio-economic costs of the HIV/AIDS pandemic will have to be weighed against the 'benefits'. At this stage the socio-economic costs are exceeding the benefits, and the fight against the pandemic must be intensified at all levels of society.

The costs are mainly that needed second-order resources will be depleted, making it an untenable situation at present and one that will impact negatively on a virtual water trade strategy. For instance, a situation where HIV/AIDS is negatively affecting household wealth has ripple effects throughout society, and will ultimately lead to a stagnation of a state's economy. If HIV/AIDS has an impact on the national economy, because of decreased financial resources, virtual water imports will not be afforded. This will subsequently impact negatively on a developing country's competitive advantage. HIV/AIDS is one of the major strategic issues that *must* be taken into account regarding a virtual water trade strategy.

Thirdly, political conditions and decisions will either stimulate positive circumstances or hindrances for the implementation of a virtual water trade strategy. The case of Zimbabwe is explicit. The land reform policy of the ZANU-PF ruling party created, ironically, a situation for the importation of virtual water agricultural commodities. Yet, at what price? Many of Zimbabwe's citizens are facing and experiencing food insecurity that is unheard of before the policy. Also, where Malawi has had a bumper crop in 1999 and 2000 it is now food insecure, after it had been influenced by international financial institutions to abandon its 'agricultural starter-pack policy'. The same is happening in Zambia, also under the influence of an international discourse regarding the adverse health risks of GMF. Thus, virtual water is not always a politically silent option for water and food scarce economies.

In the fourth place, economic capacity also plays a meaningful role within the decision of countries to go 'virtual' regarding their food requirements. If the second order resources are not available, a country will either find it difficult to import the necessary food stuffs or will not be able to afford it all. This is the case with some

SADC countries' food insecurity situation at present. Tony Allan is correct in his assertion that socio-economic development is a prerequisite for increasing second-order resources in this respect. Yet, the temporal conditions should also be taken into account. A high level of socio-economic development (that many western European countries are experiencing) for SADC's poorest countries will not happen over night. A virtual water trade strategy is not always economically invisible, as the case of economic knock-on effects, because of drought, asserts. A meaningful start for socio-economic development in Africa has been propagated by South Africa's president Thabo Mbeki contained in his African Renaissance initiative. This could become the main catalyst for socio-economic development in Africa in the long run.

Therefore, a virtual water trade strategy is, under the current environmental, political, and economical conditions not possible for many SADC countries. What then, is the power of the idea of virtual water?

Virtual water's power lies within its ability to assist in the prevention of the current situation in many SADC member states. It therefore has forecasting powers. This is evident in the warnings by the UN in 2001 that food shortages might occur in large parts of the SADC region in 2002. Bad weather, though, however unpredictable, is to be expected now and again, and tools exist which can be used for long-term forecasting. The idea of virtual water is one such method.

Because virtual water is a quantitative strategy (involving import-export and water resources data), it will help humans to forecast food shortages. This will be the case where likely events, like El Niño, HIV/AIDS, political conditions and decisions and economic capacities of countries have serious impacts on food security. For instance, if an El Niño-induced drought is forecasted for a region, it will be possible, with hindsight to look at likely scenarios that might arise. For instance, because maize is the staple in Southern Africa, the volume of water to produce maize within the region can be ascertained by using its virtual water value (VWV). In the likely event of a drought, the first order resource (water) will be scarce. Previous rainfall figures, during a drought, can be used to calculate the likely extent of the scarcity of water resources. This, combined with the VWV of maize will give an indication of how much food is needed in such a likely event.

For example, maize production, at 900 tonnes of water per tonne of maize produced, plus the volume of maize a country or region needs, equals a certain volume of water. If it is projected that the volume of water a country will receive during a season is less than the requirement, then that country will be able to plan and secure second-order resources to compensate for the shortage.

Forecasting is not an exact science. Millions of variables influence human's ability to forecast the future. Regarding this, an early warning capability, which is being worked on but is not functioning well, within SADC must factor in virtual water as an element of a coping strategy. Yet, more research is needed in the forecasting of food shortages long before they occur. By knowing these figures and combining them with rainfall figures and forecasts, governments will be able to plan ahead regarding their food imports or exports.

Virtual water calculations are an essential planning tool. These calculations will be useful in determining how seasonal water is used most efficiently to provide more food at the right times. Yet, such calculations are dependent on all other factors (environmental, political, and economical) being equal—seldom the case in Southern Africa. Nevertheless, the awareness of how water is an invisible part of the food economy is already a positive step. Once states, regional organisations, farmers, and humanitarian aid agencies have accurate information about the volume of virtual water involved in food transactions, they will be better positioned to deal with future food insecurity situations.

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15

Virtual water trade to Japan and in the world

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1. Introduction

The concept of "Virtual Water" has been developed to explain how physical water scarcity in countries in arid regions is relaxed by importing water-intensive commodities (Allan, 1997). Unit requirement of water resources to produce each commodity (hereafter called as *UW*) should be known for quantitative estimation of the virtual water trade, and there are some attempts for that (Wichelns, 2001). The database of *UW* can be utilized for assessment of water demand in the future (Yang and Zehnder, 2002).

The concept of virtual water has become popular in Japan associated with the preparation for the 3rd World Water Forum (WWF3), to be held in Kyoto, Japan, in March 2003. At first, the total virtual water import to Japan was presented in the brochure of the WWF3 as 5 billion m^3/y without any quote. After the issuing of the preliminary result by Miyake (2002), the number was increased up to more than 40 billion m^3/y in a pamphlet (WWF3, 2002). Such estimates succeeded in attracting more attention of Japanese citizen for world water issues by saying "World water issue is closely connected with Japanese daily life through the huge import of virtual water."

However, still there are a lot of uncertainties in determining *UW*, probably because there are some alternatives of rational definition on virtual water. In this study, the way of estimating *UW* for grains, meat, and industrial products by the research group of the authors is presented in sections 2 and 3. Using these results, the annual importing flow of virtual water to Japan is shown using the *UW* in 4.

It should be noted that *UW* is highly dependent on the crop yield per area and different in each country and changes in time. Since the original idea of the virtual water is how much water resources in the importing country can be saved, *UW* of improving country should be used to estimate the how much virtual water is imported. If *UW* of exporting country is multiplied to the exporting amount of goods, that is the "really required water" used to produce the goods. In this aspect, it is obvious that "virtual water" is "virtually required water" in its original sense, and we may call "really required water" as "real water" in the same way. From this point of view, "real water" in exporting countries becomes "virtual water" in importing countries, and generally they do not correspond quantitatively. The implication of virtual water trade in the water balance on the global scale is presented and discussed in section 5, and section 6 summarizes the remarks.

2. Unit requirements of water resources for grains

Total water volume required to produce grains (W) was considered when estimating the unit requirement of water resources to produce grains. From some point of view, only the irrigation water (*blue water*) withdrawn to produce the grain should be considered. In this study, total water needed for crop cultivation was accounted, which may consists both a part of precipitated water over the cropland and irrigated water. It should include water for transpiration from the crop, water evaporating from the cropland, and even water infiltrating water into the ground, if necessary for the cultivation. The total amount needed for the crop growth was estimated by daily requirement of water W_d and the term of growth N_d for each crop.

Required water amount was assumed to be 4mm per day for all the crops but paddy, which requires inundation for ordinary way of farming and daily value was set to 15.0 mm per day. The number of days for growing was taken from various textbooks mostly written in Japanese. Then, *UW* can be derived from

$$UW_r = \frac{W_d \times N_d}{Y} \qquad (1)$$

where Y is the crop yield per area. UW_r estimated from Eq. 1 is unit requirement of water resources to produce the crop including less valuable or wasting part of the plant, e.g. bran.

With the yield ratio re of the edible part of the plant to the gross weight,

$$UW_e = \frac{W_d \times N_d}{Y \times r_e} \tag{2}$$

corresponds to the how much water resources are required per edible weight of grains. UW_e is suitable to assess how much water resources are embodied in daily food. Further, most of the trade statistics use unmilled (unpolished) weight of grains and we have to consider the ratio r_t of unmilled grains to the total weight when yield statistics are measured.

$$UW_t = \frac{W_d \times N_d}{Y \times r_t} \tag{3}$$

Therefore UW_t should be used when international virtual water trade is discussed. Targeting to estimate the total virtual water import to Japan, major grains related to Japan were picked up, and UW_r , UW_t , and UW_e were estimated and shown in Table 2.1.

Table 2.1. Required water resources (m^3) to produce unit weight (t) of grains for Japan: UW_r for rough yield, UW_t for trade statistics, and UW_e for edible part only.

	Yield	Water demand	Total period	Total water	Rough yield	Yielding ratio	For Trade	Yielding ratio	Edible part
	Y	W_d	N_d		UW_r	r_t	UW_t	r_e	UW_e
	t/ha	mm/day	day	m^3	m^3/t	%	m^3/t	%	m^3/t
rice	6.46	15	100	15,000	2,300	72	3,200	65	3,600
wheat	3.48	4	135	5,400	1,600	100	1,600	78	2,000
soybean	1.73	4	110	4,400	2,500	100	2,500	100	2,500
maize	4.29	4	100	4,000	900	100	900	50	1,900
barley	3.61	4	110	4,400	1,200	100	1,200	46	2,600

Crop yields are taken from FAOSTAT and averaged for 1996 through 2000, and the values are for Japan except for maize since there is only negligible production of maize in Japan. The mean value in the world of crop yield for maize was used in Table 2.1.

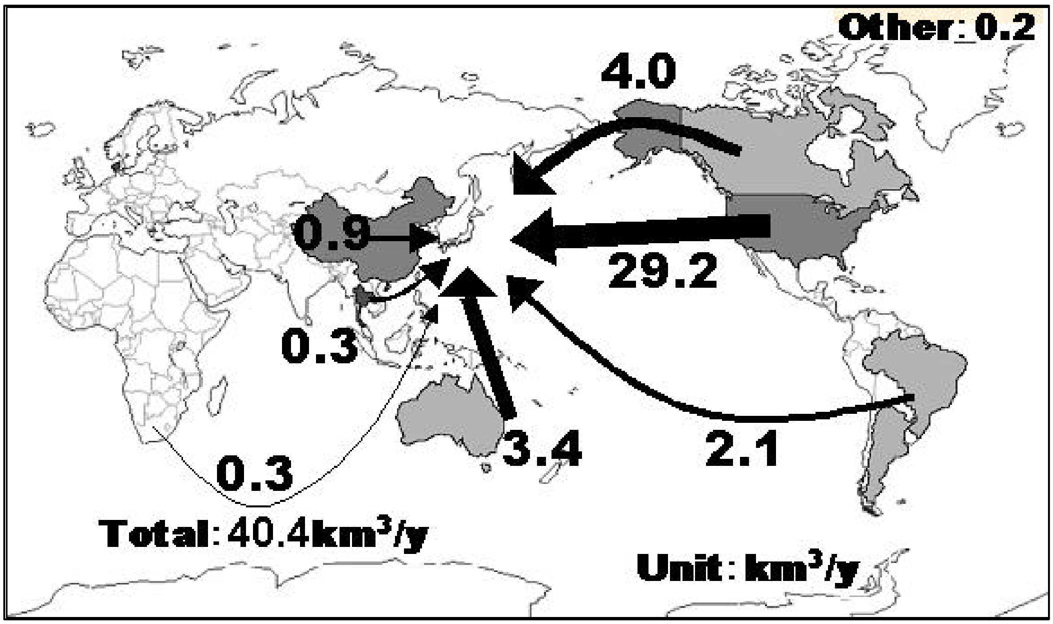

Figure 2.1. Annual virtual water import to Japan (m^3/y) embodied in grains. Based on crop yields in Japan for 1996-2000 and trade statistics for 2000.

The numbers of "irrigation water requirement" (m^3/ha) in Table 2.1 in Wichelns (2001) are 20,952 for rice, 3,786 for wheat, and 6,429 for maize, and these values are not too far from the estimates in Table 2.1. From macroscopic point of view, Japanese agricultural withdrawals are approximately 59 billion m^3/y and 95% of it is used for irrigating paddy field. Total crop yield of rice is approximately 11.2 million t/y in 1998 for unmilled rice, and it calculates UW_t = 5,000 m^3/t. This value is higher than the estimate in Table 2.1, it should be mainly because the statistics of Japanese irrigation withdrawal is based on the water rights and the value includes the period without cultivation. Even though the accuracy may not be high enough, we believe the values in Table 2.1 are not far from reality and should be valid for further discussions on the virtual water trade. The annual import of virtual water through grains and soybean is presented in Figure 2.1.

3. Unit requirements of water resources for meat

The unit requirement of water resources for meat was estimated based on the virtual water embodied in cereals to feed livestock. Approximately 3 million t of meat in total (beef, pork, and chicken) are produced annually in Japan, and only 500 million t of water resources are used for livestock husbandry. This amount is also considered in the following estimates even though not substantial.

3.1. UW for concentrate

At first, the contents of the fodder are taken from a table for 1999 on a web site (URL at http://www.tge.or.jp/japanese/guide.j/products/sm_m02.j.html), and unit water requirement per weight are calculated (Table 3.1). The unit requirement of water resources for concentrate UW_f was estimated with the mixed ratio b_k of fodder k with UW_k .

$$UW_f = \sum_k b_k UW_k \tag{4}$$

It was assumed $UW_k = UW_r$ for maize, wheat, and rye. In the case of Japan, sorghum is regarded similar to maize, and the same UW_k is used for sorghum.

Table 3.1. Virtual (required) water per weight of fodder for each livestock (m^3/t) for Japan.

	UW m^3/t	Hen %	Broiler %	Pork %	Dairy cattle %	Beef cattle %
maize	900	55	46	46	37	38
soybean meal	2,000	13	21	14	12	5
sorghum	900	5	18	17	3	4
wheat bran	50			1	5	15
rye	1,200			1	2	15
wheat bran	1,600			1	1	
other	0	27	15	20	40	23
UW **(m^3/t)**		800	996	876	643	666

The *UW* of by-products are allocated to their economical values.

$$UW_{sub} = \frac{P_{sub}}{P_{main} + P_{main}} \times UW \tag{5}$$

Where UW_{sub} is the unit water resources requirement of byproduct, and P_{main} and P_{sub} are the total price of main product and byproduct per unit material. For example, let main product of soybean be the soybean oil and the byproduct be the soybean meal. Eleven pounds of soybean oil and 44 pounds of soybean meal are taken from 60 pounds of soybean. Soybean oil and soybean meal are assumed to have a price of 15c/pound and 200$/pound respectively. With unit conversion and Eq. 5, UW_{main} of soybean (oil) and UW_{sub} of soybean (meal) were estimated as 700m^3/t and 2,000m^3/t, respectively. Note there are weight losses in the process, and sum of UW_{main} and UW_{sub} is larger than original *UW*. The *UW* for fodder of livestock seems to depend on how much "other" is included. Since "other" corresponds to fishmeal, feather meal, fat, treacle, powdered bones and meat, it was assumed that water resources consumption for "other" can be neglected.

Unit water requirement for roughage was estimated in the similar way as crops. Grasses for roughage are grown for 90 days and yield per area is 35 t/ha (raw) and 7 t/ha (dry). Therefore from Eq. 1 and r = 100%, *UW* of raw and dry roughage are 100 m^3/t and 500 m^3/t, respectively.

3.2. General expression of UW for meat

UW for cattle products were estimated by

$$UW = \frac{PW + FW + DW}{M \times r} \tag{6}$$

Where *PW*, *FW*, *DW*, *M*, and *r* are *UW* embodied in child livestock, total *UW* embodied in the fodder fed during the livestock's life, *UW* directly used to take care of the livestock, weight when it was terminated, and the loss rate by shaping.

PW is the *UW* a child livestock inherit from mother when it is born, and estimated as

$$PW = \frac{aMW}{n} \tag{7}$$

Where *n* is the total number of babies a mother livestock has in her life. *MW* is the total water usage for the mother livestock and *alpha* is the parameter how much percentage of *MW* can be recognized as used for babies. If the mother livestock is not used for meat after her life, such as the cases for chicken and pork, *alpha* = 1.0.

Since,

$$MW = PW + FW_m + DW_m = \frac{aMW}{n} + FW_m + DW_m \tag{8}$$

$$MW = \frac{n}{(n-a)} + (FW_m + DW_m) \tag{9}$$

Where FW_{m} and DW_{m} are water used to feed and take care of the mother livestock.

The total water usage embodied in the fodder *FW* is calculated as

$$FW = UW_c E_c + UW_g E_g \tag{10}$$

Where UW_{c} and UW_{g} are the *UW* for concentrate and roughage, respectively.

From the feeding fodder a day at each life stage *i* for concentrate e_{ci} and e_{gi} and days at each life stage N_i, total fed concentrate E_{c} and roughage E_{g} are calculated as

$$E_c = \sum_i e_{ci} N_i \tag{11}$$

$$E_g = \sum_i e_{gi} N_i \qquad (12)$$

and, of coarse, the total growing duration N_d satisfies

$$N_d = \sum_i N_i \qquad (13)$$

DW was estimated by

$$DW = W_d \times N_d \qquad (14)$$

with W_d of direct water usage a day.

3.3. UW for chicken and egg

The variety of chicken for eggs and meats are different, however, the *UW* for egg was estimated first with *alpha* = 1:0, and it was used for *PW* of chicken for meats in this study.

A hen starts spawning an egg a day, 150 days after its birth. Even though it can spawn totally 500 through 600 eggs a life, but commonly terminated when they spawn 400 eggs. Therefore it was assumed that a model hen lives 550 days and spawns 400 eggs.

A chick is fed 2.1 kg of fodder during the first three weeks, and 1.25kg a week, afterwards. Therefore totally 95kg of fodder, namely 76 m^3 of water is used for a hen. The direct water usage was set to be Wd =0.65 liter a day, and DW =0.36 (m^3).

Table 3.2. Virtual (required) water per weight of meat, egg, and milk (m^3/t) for Japan.

	Killed weight	Dressed carcass	Meat
Chicken*	2,400	3,000	4,500
Pork	2,900	4,100	5,900
Japanese Beef	9,600	15,300	21,400
Domestic Beef	8,100	13,600	19,900
Beef (average)	8,800	14,400	20,700
Egg	3,200	(190 liter/egg)	
Milk	560	m^3/t	

* 7,000 (m^3/t) for white meat of chicken.

Since *alpha* = 1.0 and *n* = 400, *PW* =190 liter an egg, and with assuming the weight of an egg to be 60g, *UW* for egg is 3,200 m^3/t.

Majority of chicken meat is taken from broilers. A chick is given totally 5.5 kg (2.1kg of fodder for hen, and 3.4kg of fodder for broiler) of fodder in 7 weeks and shipped with its weight of 2.5 kg. The fodder corresponds to 1.7 m^3 and 3.4 m^3 of virtually required water, respectively, and *DW* =0.032m^3 of water is used directly for a chicken in N_d =49 days. Therefore totally 5.3 m^3 of water is used, and *UW* for a chicken is approximately 2,300 m^3/t with killed weight of 2.25kg. The weight loss with shaping is 78% for dressed carcass and 53% for removed carcass, these values yields *UW* of 3,000 m^3/t and 4,500 m^3/t, respectively. In the case of white meat of chicken, yielding ratio is 34% and *UW* becomes 7,000m^3/t.

3.4. UW for pork

A mother pig is raised only for breeding, and the required water embodied in the gruntling is estimated from the direct and indirect water given to the mother pig. It was assumed mother pig is only for breeding and not used for meat consumption (*alpha* = 1.0). A mother pig delivers 10 gruntlings a birth and 6 times of birth for a life (n = 60). Milk is given for the first month of a mother pig, and 2kg of fodder is given everyday afterwards. A mother pig needs 3.2 kg/day of fodder during the last 35 days of her pregnant period, and 5.5 kg/day for the first 30 days of raising gruntlings. Since typically the first birth is at her 12 months and the interval of the birth is 6 months, a mother pig takes totally 3,412 kg of fodder, and it corresponds to approximately 2,989 m^3 of virtually required water embodied in the fodder.

N_d for mother pig is 1,290 days, and direct water usage for a pig was set to W_d =25 liter a day, and DW =32 m^3. Therefore the required water per gruntling is approximately PW =51 m^3 from Eq. 9.

A pig for meat consumption is raised for 6 months with 300kg of fodder, corresponds to 263 m^3 of required water, and weighs 110kg. Direct water used for raising a pig is approximately 20 to 30 liter a day, and approximately 5 m^3 for 6 months. Therefore totally 319 m^3 of water is used to raise 110kg of pig, and *UW* for a pig is approximately 2,900 m^3/t. The weight loss with shaping is 70% for dressed carcass and 49% for removed carcass, these values yields *UW* of 4,100 m^3/t and 5,900 m^3/t, respectively.

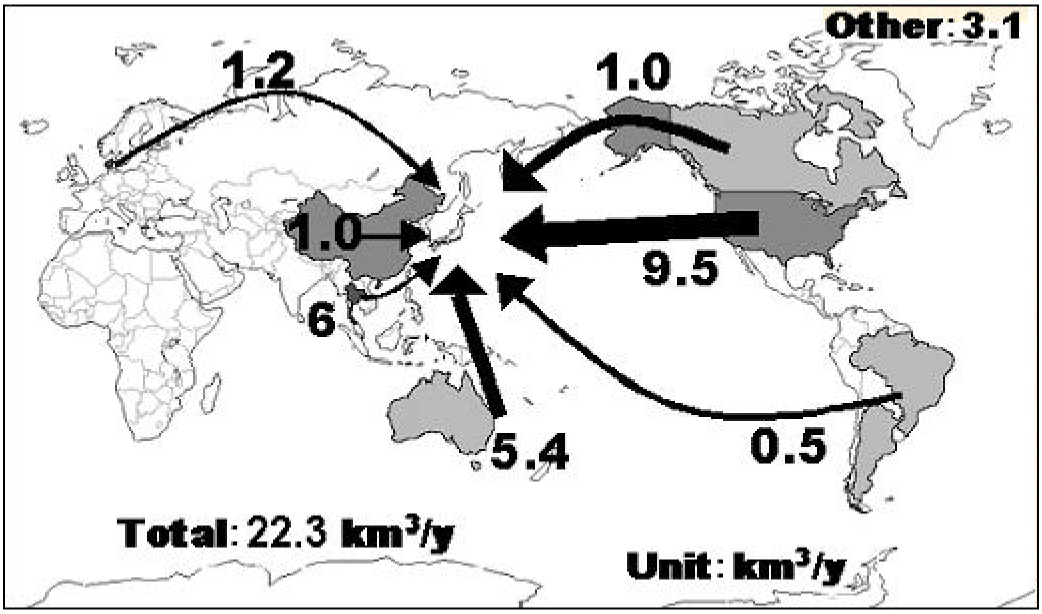

Figure 3.1.Annual virtual water import to Japan (m^3/y) embodied in meat. Based on crop yields in Japan for 1996-2000 and trade statistics for 2000.

3.5. UW for beef

No significant difference in raising a pig or a chicken was found in region by region, however, way of raising a cow seems quite different in each country. In Japan, at least there are two kinds of beef. "Japanese Beef" (called WAGYU) is taken from beef cattle with fattening, and "Domestic Beef" is a dairy cattle with castration and fattening.

First, *UW* for "Japanese Beef" is estimated. A mother cow is made pregnant when she is 17 months old delivers 6 times of birth for 9 months each with 13 months intervals, and finally terminated with 4 months of fattening.

The total indirect water put to the mother cow was allocated to the mother's meat and her calf with assuming that all the fodder during the mother cow is pregnant and giving milk to her calf is for the calf and rest of the fodder is used for the meat when she will be terminated. Then *alpha* becomes 0.75. Since n = 6, E_{cm} =5.5 (t) and E_{gm} =21.28 (t), FW_{m} =14,306 m^3.

Direct usage of water for a cow is set to 60 liter a day, and DW_{m} =178 m^3. Then MW =16,553m^3 and PW =2,069 m^3 are derived.

A baby calf for meat is raised 10 months with 2.2kg of concentrate and 0.4kg of roughage a day, and concentrate is increased up to 4.5kg a day for 2 months before its trade. After the trade, the baby calf is raised for 20 months with fattening. Then *FW* becomes 4,421 m^3. Even though meat from a fattened mother cow after her several times of birth is also categorized, as "Japanese Beef" and *UW* should be different from the simply raised cow, this was not estimated here. With consideration of 60 liter of direct usage of water a day, totally 6,544 m^3 of water is used to obtain 680kg of "Japanese Beef." It corresponds approximately 9,600 m^3/t of *UW*. The weight loss with shaping is 63% for dressed carcass and 45% for removed carcass, these values yields *UW* of 15,300 m^3 /t and 21,400 m^3 /t, respectively.

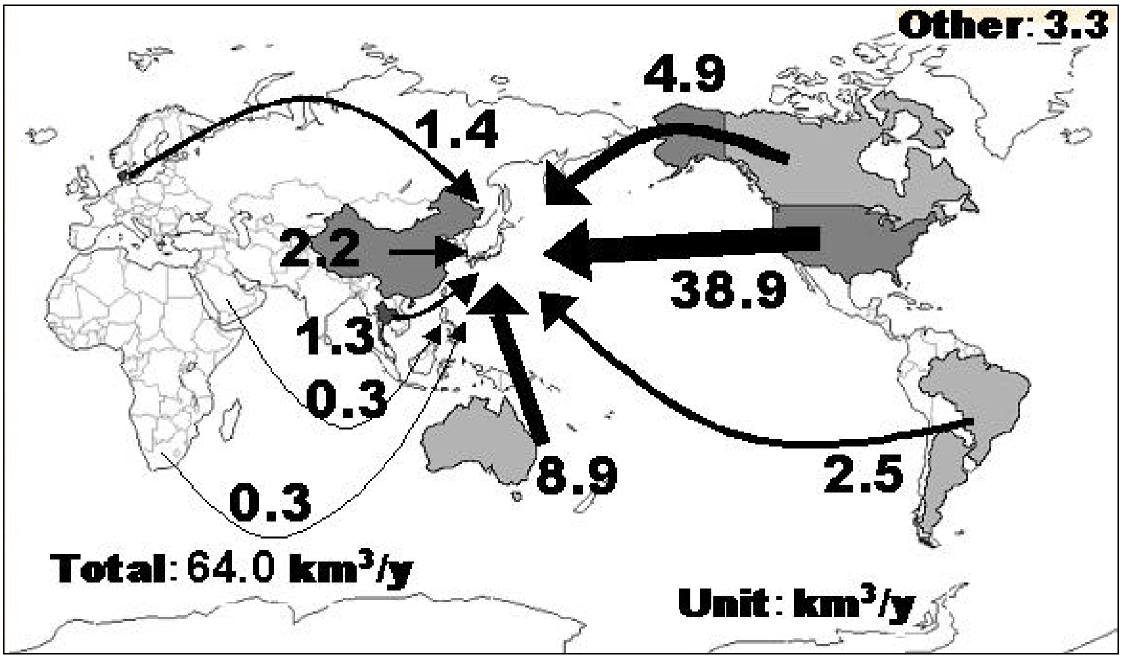

Figure 3.2. Annual virtual water import to Japan (m^3/y) in 2002 embodied in grain, meat, and industrial products.

For the case of diary cattle, it delivers 4 times of birth with interval of 400 days with milking period of 320 days for each birth. The first delivery is at its 27 months and a model diary cattle lives for 7 years. During each milking period, 7,000 kl of milk are obtained. Roughage of 2,389kg is given to the first pregnancy and 12kg a day of roughage is given to a diary cattle except for the last two months of pregnancy with 15.6kg a day. In addition to that, 1kg of concentrate is given for 2kg of milk during the milking period. The direct water usage of 135 liter a day and 75 liter a day of water is used for cooling milk. These values are also considered. Since a calf is a byproduct of diary cattle, virtually required water for roughage during the pregnant period was allocated for the required water of a calf, and remaining water put for diary cattle was considered to be the required water of milk. Required water was allocated evenly for calf and milk during the period when mother cow is pregnant and also milking.

Then *alpha*=0.35 was derived.

Considering $n = 4$, N_{dm} =2,330 days, N_{milk} =1,280 days, E_{cm} =14 t, E_{gm} =24.85 t, FW_{m} is estimated as 21,429 m^3.

DW_{m} is 402 m^3 and *MW* becomes 23,934 m^3. With *alpha* =0.35, *PW* =2,094 m^3 is obtained.

Since 15,557 m^3 of water is required to obtain 28,000 liter of milk, UW_{milk} is approximately 560 m^3/t.

Enervated diary cattle is given 1,230kg of roughage and *FW* =4,018 m^3. Considering *DW* =33m^3 with direct water use of 55 liter/day during fattening, totally 6,145 m^3 of water is virtually and really required to raise 755 kg of a cow, and *UW* is approximately 8,100 m^3/t. The weight loss with shaping is 60% for dressed carcass and 41% for removed carcass, these values yields *UW* of 13,600 m^3/t and 19,900 m^3/t, respectively.

Table 3.3. Real and virtual water usage of Japan (km^3/yr). Unit water requirement UW for Japan was used for domestic production and importing amount.

	Domestic water usage	Importing virtual water
Rice	31.3	2.4
Wheat	1.1	9.4
Soybean	0.6	12.1
Maize		14.5
Barley	0.3	2.0
Sub total	*33.3*	*40.4*
Beef	7.5	14.0
Pork	5.1	3.6
Chicken	3.6	2.5
Milk and dairy	4.6	2.2
Sub total	*20.8*	*22.3*
Total	54.1	62.7

It is meaningless to apply either *UW* of "Japanese Beef" or diary cattle, weighted mean value of *UW* following to the production of dressed carcass in Japan was used for *UW* when estimating the virtual water import to Japan. Annual virtual water trade to Japan through meat is presented in Figure 3.1.

4. Total virtual water import to Japan

When considering the total virtual water import to Japan, the virtual water trade associated with the industrial products was estimated from the fresh water usage per shipping price. This is certainly underestimate the required water embodied in industrial products since no required water associated with the raw materials are not considered. Therefore the total virtual water import to Japan was estimated to be only 1.3 billion m^3/year. Of course, in the case of industrial products, "real water" export from Japan to the world is more than "virtual water" import, and it is estimated as 1.4 billion m^3/year. Any case, the virtual water trades through industrial products are comparatively small to agricultural products, and total virtual water trade (import) to Japan is estimated based on through grains and meat.

Figure 3.2 shows the flow of virtual water to Japan. Total virtual water import is approximately 62.7 billion m^3/y, and it is more than annual withdrawal of irrigation water in Japan (59 billion m^3/y). Most of the virtual water is coming from USA and Australia through maize, beef, wheat, and soybean. Since 70% of maize, most of soybean meal, and half of barley are used for raising livestock in Japan, in a sense, it can be said that most of the virtual water import to Japan is for meat diet.

Table 3.3 compares the domestic usage of water resources (real water usage) and the virtual water import for each crop and meat. The self-sufficiency ratio of water resources is approximately 46%, and it is close to the self-sufficiency ratio of dietary in Japan by calorie basis.

Domestic water usage in Japan is approximately 700 m^3/capita/y consists of 130 m^3/capita/y for municipal water, 110 m^3/capita/y for industrial water, and 460 m^3/capita/y for agricultural water. The importing virtual water to Japan accounts as approximately 500 m^3/capita/y, and it is comparable to the domestic water usage of Japan.

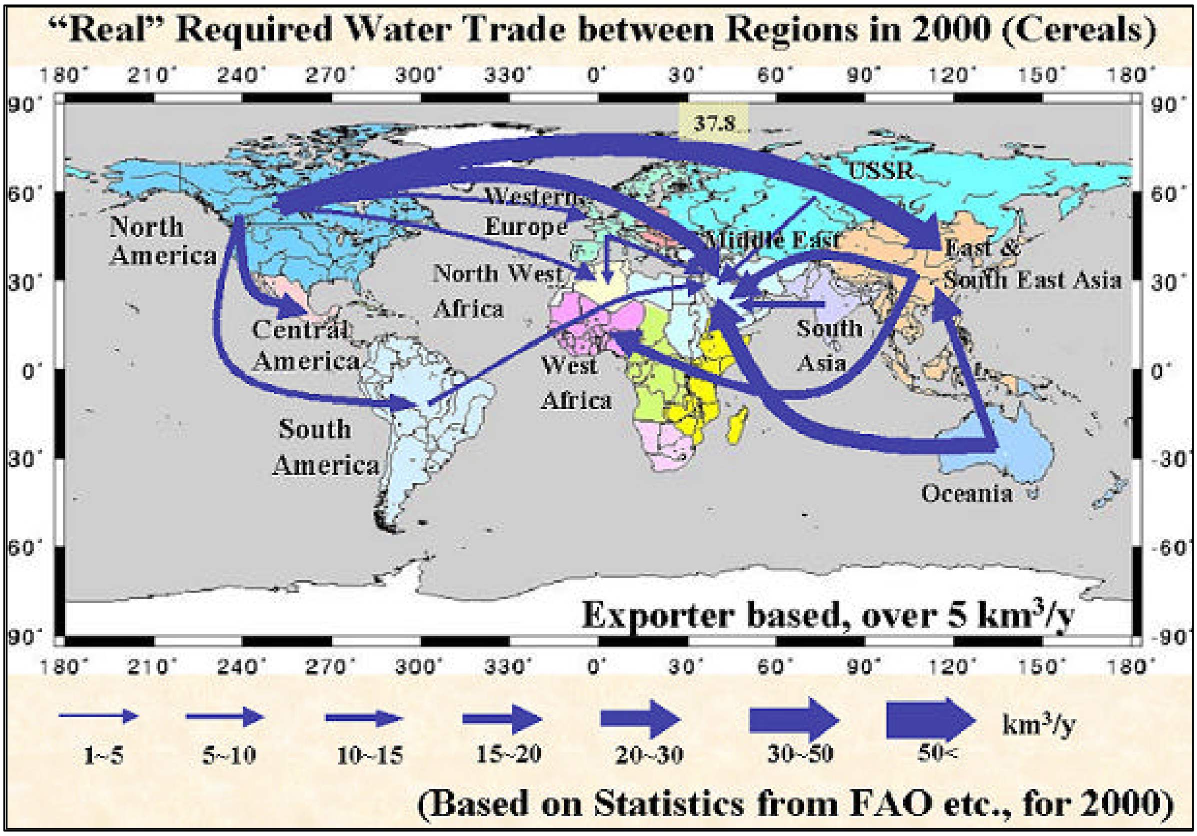

Figure 4.1. Annual really required water (real water) trade (km^3/y) for 2000.

Of course, in the case of Japan, physical water stress is not the major reason importing virtual water, but lack of cropland demands the "virtual land" overseas.

5. Assessing virtual water flow in the world

Based on the FAOSTAT with *UW* presented in previous sections, global "virtual" and "real" water flows associated with cereal were estimated for 2000 in Figures 4.1 and 5.1. Virtual water trade is estimated using crop trade and yield of maize, wheat, rice, and barley from FAOSTAT (taken at August 2002) and soybean is excluded from the estimates. *UW* was modified from Japanese value presented in sections 2 through 4 changing the yield per area in each country. If no statistics is available for particular crop, world average was adopted.

As stated in the beginning, in the case of bilateral trade, there are two *UW* values based on the crop yields in exporting country and importing country. The *UW* based on the crop yields in importing country should be used to estimate the virtual water of its original sense. Importing amount of goods multiplied by *UW* tells how much domestic water resources could be saved due to the import of the goods.

On the contrary, the exporting amount of goods multiplied by *UW* based on the crop yields in exporting country should correspond to the real water resources used to produce the goods.

Generally crop yields in exporting country is higher than that in importing country. Therefore *UW* in exporting country is smaller than *UW* in importing country. Consequently, "real water" in exporting countries tends to smaller than "virtual water" in importing countries.

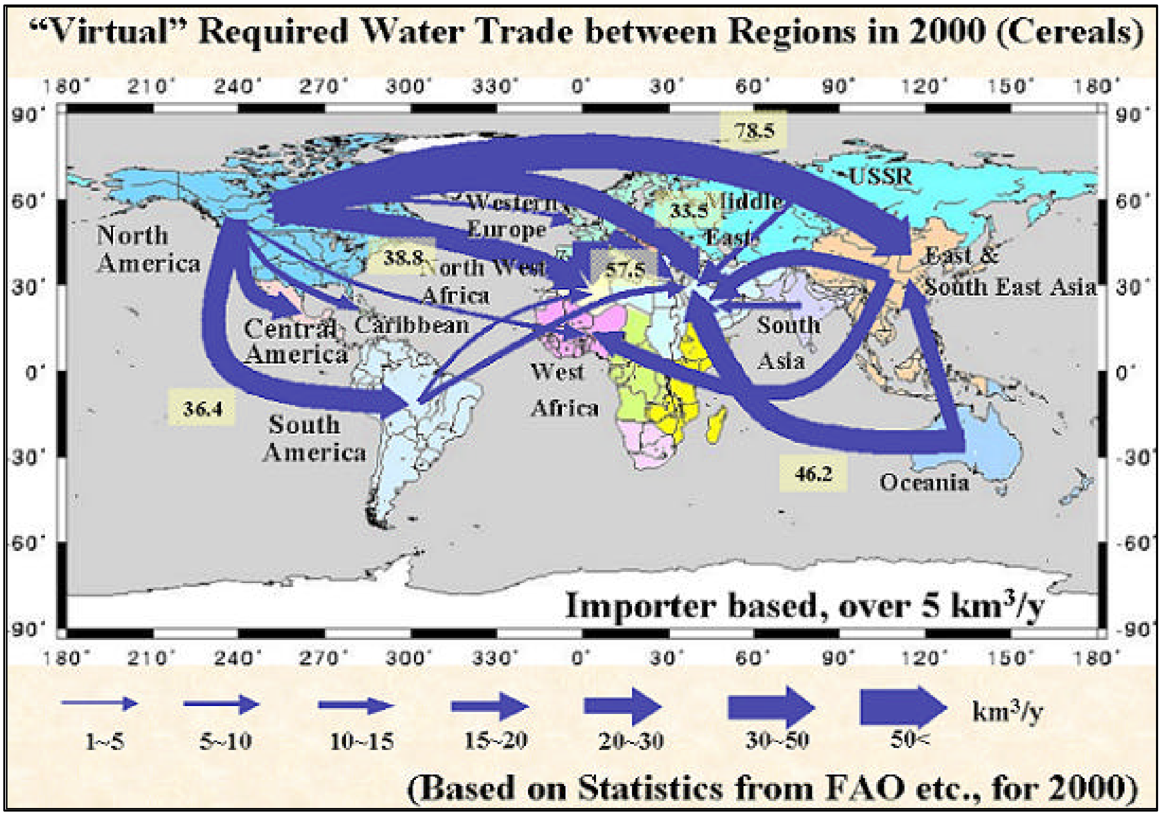

Figure 5.1. Annual virtually required water (virtual water) trade (km^3/y) for 2000.

All the virtual and real water flow were estimated for each country where statistics are available for 1990 and 2000, but the world is classified into 16 regions and numbers are summarized in Figures 4.1 and 5.1 and the Tables in the Appendix. They are North America, Central America, South America, Caribbean, Western Europe, Eastern Europe, Near East, South Asia, East and South-East Asia, Oceania, Eastern Africa, Western Africa, North Western Africa, Central Africa, and South Africa.

Figures 4.1 and 5.1 presents the annual "real" and "virtual" water flow. The thickness of the arrows corresponds to the flow volume, and major water trades are indicated. As obvious from the figures, Middle East, North West Africa, and East & South East Asia are gathering plenty of "real" and "virtual" water.

Table 5.1 shows the world summary of comparison between "virtual water" and "real water" in km^3 /y. Since more comprehensive statistics is available for exporting and importing amount of goods without destination and origin, the total value in Table 5.1 is larger than the values in the Tables in Appendix (and Figures 4.1 and 5.1).

Total virtual water trade (imported virtual water) is approximately 1,140km^3/y, however only 680km3 of real water should have been used to export the cereals, soybean, and meat. It means if these foods were produced in the importing country, nearly double amount of real water should have been needed but it was saved owing to the virtual water trade.

There are certain percentages of import from unidentified country in the statistics, and approximately 20% of exported rice and barley, a few percent of exported maize and wheat are not included in Table 5. Therefore the total volume of virtual water and real water may not be easily compared with other estimates.

Even there are such difficulties in comparisons, the virtual and real water transfer according to major cereal trade in Table 5.1 is compared with the mean values Hoekstra and Hung (2002) estimated for 1995-1999. Their estimates are within the range of virtual water and real water, but closer to "real water" particularly for wheat and rice. It is reasonable since they used the crop yield data of exporting country for their estimates of *UW* ("virtual water content" in their report).

Table 5.1. Global virtual and real water transfer (km^3/y) associated with crop and meat trade. Virtual water is estimated using the required water in the importing country, and real water is estimated with the required water in the exporting country.

	Global water trade	Global water trade	Saved		Virtual water trade
	Virtual (km^3/y)	Real (km^3/y)	Volume (km^3/y)	ratio to VW (%)	IHE* (km^3/y)
Maize	127.0	51.7	75.3	59	61.4
Wheat	464.2	270.9	193.3	42	209.8
Rice	185.6	110.7	74.9	40	106.8
Barley	91.5	38.4	53.2	58	34.0
Cereal total	868.3	471.7	396.7	46	412.0
Soybean	118.1	84.0	34.1	29	
Chicken	37.4	25.3	12.0	32	
Pork	28.3	19.6	8.7	31	
Beef	86.2	82.4	3.9	5	
Meat total	151.9	127.3	24.6	16	
Total	1,138.3	683.0	455.4	40	

** IHE: Hoekstra and Hung (2002)*

This kind of estimates will support the globalization of trade from economical point of view. Actually, the large amount of saving in real water due to virtual water trade globally can be explained by the comparative advantage of cereal production in terms of water. This is apparent true for crops and soy bean since water resources for these goods are virtually saved approximately 50% by virtual water trade. It is interesting to see this saving is less for chicken and pork (approximately 30%) and not significant for beef (approximately 5%). It is because the *UW* for pasture grass is not as much different as the *UW* estimated for crops.

Saving water resources should be commonly appreciated, however, one should be careful to interpret the results since the idea of virtual water implies only the usage and influence of water and no concerns on social, cultural, and probably environmental implications. In spite of that, Table 5 claims that transferring virtual and real water from water efficient region to water inefficient region will save (or increase) the available water resources globally.

Figure 5.2 illustrates the temporal evolution of the virtual and real water trade in the world for 1961-2000. The estimates consider the change in the export and import in each country, and the change in the crop yield. The change in the crop yield changes the *UW* of meat, as well. Therefore the increase in the total virtual and real water trade in Figure 6 should be smaller than that of the increase of international trade in 1961-2000.

The virtual water trade in 1961 is estimated to be one third of the current (year 2000) situation, however, the real water trade associated with the international trade of crop and meat in 2000 did not increase twice as much as that in 1961. As a residual, the virtual water gain, how much water resources were saved by the transfer of real water into virtual water, increased significantly. Actually, the real water export was close to the virtual water import globally, and the virtual water gain is estimated to be less than 30 km^3/y in 1961. This should reflect the increase of the mean crop yield in the world, and it may imply the contribution of the virtual water trade to save the water resources usage in the world. Some detailed analysis of that point is shown in the next subsection.

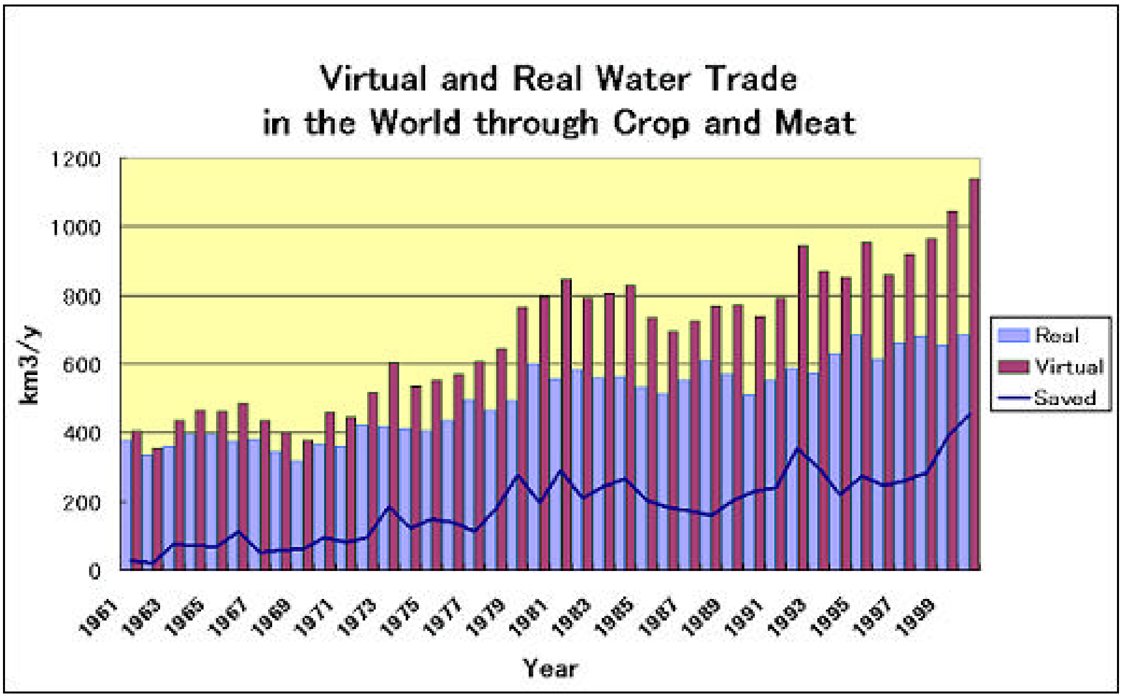

Figure 5.2. Temporal evolution of annual virtual and real water trade in the world from 1961 through 2000. Trade statistics between countries and crop yield are changing year by year.

5.1. Contribution of virtual water for the reduction of water stress

Available water resources per capita W in each country are assessed with natural available water from Oki et al. (2001). Water stress in each country is classified using the available water resources per capita per year (Shiklomanov, 1997) into:

- "catastrophically low" ($W < 1{,}000$ m^3/c/y),
- "very low" ($1{,}000 < W < 2{,}000$ m^3/c/y),
- "low" ($2{,}000 < W < 5{,}000$ m^3/c/y), and
- "average or more." (5,000 m^3/c/y $< W$)

There are 26 countries classified as "catastrophically low" with naturally available water resources W_n. When virtual water trade is considered, all the three countries with GDP per capita > 20,000USD moved into the "very low" or "average or more" class. For GDP per capita > 5,000USD, 3 remained in "catastrophically low" but other 9 moved up and relaxed the water stress. For GDP per capita > 1,000USD, all the countries also moved up. However, GDP per capita < 1,000USD countries, 3 countries remained in the "catastrophically low" and only 2 countries could relaxed its class. It is clear that relatively rich countries can compensate the shortage of water by importing virtual water, however, poor countries cannot.

6. Concluding remarks

Unit requirement of water resources to produce each commodity *UW* was estimated for crops, meats, and processes in industry. With this *UW*, required water embodied in goods can be estimated. Crop yields per area are quite different in each country and changes in time. Since *UW* depends on crop yield, *UW* changes in time and space, as well.

Total required water embodied in exporting goods can be estimated with total weight of the goods and *UW*. Total amount of "real water" used in the exporting country is derived if *UW* of the exporting country is used. On the contrary, "virtual water" how much water resources could have been saved can be estimated if *UW* of the importing country is used. Required water generally flows from where crop yields are higher and *UW* is lower to the place of low crop yields and high *UW*. From the detailed analysis, that is true and it can be recognized as the comparative advantage in water resources.

The concept of virtual water is also useful to increase the awareness on the consumption of water resources in a daily life. Therefore life cycle assessment of all the goods in the society should be challenged in order to extrapolate the idea of virtual water, particularly to industrial products. Even though that may be too ambitious at present, somehow similar research has been done for energy consumption and release of carbon dioxide.

Another challenge should be the estimate of "virtual" and "real" water transfer with higher spatial resolution than countries. Accurate estimation could be impossible but adopting an appropriate proxy data to distribute the country statistics will help visualizing the global flow of virtual and real water.

It is impossible to assess the impact of irrigation to sway the *UW* value by current procedure to estimate *UW*. Further investigation and establishment of database of *UW* for various products are urged for further assessment of virtual water transfer in the world and how that changes the regional demand and supply of water and food.

Acknowledgments

The authors would like to thank all the data providing agencies and bodies. This research is partially supported by the Core Research for Evolutional Science and Technology of the Japan Science and Technology Corporation, and the No.5 project of the Research Institute for Humanity and Nature, "Integrated management system for water issues of global environmental information library and world water model."

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Appendix. The virtual and real water flows among 16 world regions *(estimated for each country where statistics are available for 1990 and 2000).*

Real Water (really required water) Trade in 2000

Importer Exporter		Africa						Asia				Europe			America			Caribbean	Oceania	Exported Real Water(km^3)
		Afr Dpd	C Afr	E Afr	NW Afr	S Afr	W Afr	ME	Asia Dpd	E/SE Asia	S Asia	USSR	E Europe	W Europe	C Amr	N Amr	S Amr	Caribbean	Oceania	
Africa	Afr Dpd	0	0	0.04	0	0	0	0.05	0.89	0.08	0	0	0	0	0	0	0	0	0	1.06
	C Afr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	E Afr	0	0.1	0.15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25
	NW Afr	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0.01
	S Afr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	W Afr	0	0	0	0	0	0.09	0	0	0	0	0	0	0	0	0	0	0	0	0.09
Asia	ME	0	0	0.02	1.11	0	0	0.82	0.29	0.05	0	0.29	0.15	0.14	0	0	0	0	0	2.87
	Asia Dpd	0	0	0	0	0	0	0	0	0.62	0	0	0	0	0	0	0	0	0	0.62
	E/SE Asia	3.77	0.63	1.95	0.24	0	14.93	15.9	1.66	18.65	0.46	0.27	0.68	2.53	0	2.64	0	0.71	0.68	65.7
	S Asia	0.9	0.58	0.98	0.17	0	0.34	12.92	0.01	1.7	3.58	0.11	0.01	1.63	0	0.51	0	0	0.06	23.5
Europe	USSR	0	0	0	0.13	0	0	5.44	1.01	0.39	0.01	20.98	0.34	1.14	0	0.1	0	0.11	0	29.65
	E Europe	0	0	0	0.06	0	0	0.31	0.01	0	0	0.17	1.58	0.12	0	0	0	0	0	2.25
	W Europe	0.05	0.76	0.56	6.05	0	1.13	7.77	0.33	0.25	0.09	0.68	1.27	0.2	0.02	0	0.31	1.02	0.01	20.5
America	C Amr	0	0	0	0.12	0	0	0	0	0	0	0	0	0.54	0.11	0.04	0.01	0	0	0.82
	N Amr	0.57	0.56	1.76	7.89	0.07	4.54	23.44	19.79	17.99	2.21	1.09	0.38	6.49	15.83	6.27	10.92	3.89	0.08	123.77
	S Amr	0.7	0.01	0.77	1.57	0	0.2	8.02	0.74	1.65	0.06	0	0.73	2.89	0.14	0.01	22.05	0.16	0	39.7
Caribbean	Caribbean	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0.01
Oceania	Oceania	0.37	0	2.08	0.24	0	0	20.5	3.16	13.61	1.4	0	0	0.91	0	0	0.04	0	1.64	43.95
Imported Real Water (km3)		6.36	2.64	8.31	17.58	0.07	21.24	95.17	27.89	54.99	7.81	23.59	5.14	16.59	16.1	9.57	33.33	5.9	2.47	354.75

Virtual Water (virtually required water in importing country) Trade in 2000

Importer Exporter		Africa							Asia				Europe		America			Caribbean	Oceania	Exported Virtual Water(km^3)
		Afr Dpd	C Afr	E Afr	NW Afr	S Afr	W Afr	ME	Asia Dpd	E/SE Asia	S Asia	USSR	E Europe	W Europe	C Amr	N Amr	S Amr	Caribbean	Oceania	
Africa	Afr Dpd	0	0	0.11	0	0	0.01	0.02	0.83	0.05	0	0	0	0	0	0	0	0	0	1.02
	C Afr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	E Afr	0	0.18	0.24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.42
	NW Afr	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0.01
	S Afr	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01
	W Afr	0	0	0	0	0	0.08	0	0	0	0	0	0	0	0	0	0	0	0	0.08
Asia	ME	0	0	0.03	4.11	0	0	0.57	0.49	0.16	0	0.56	0.14	0.1	0	0	0	0	0	6.16
	Asia Dpd	0	0	0	0	0	0	0	0	1.33	0	0	0	0	0	0	0	0	0	1.33
	E/SE Asia	4.29	1.51	3.98	0.56	0	21.73	29.83	0.93	18.08	0.58	0.31	0.62	1.11	0	0.99	0	1.08	0.41	86.01
	S Asia	1.15	2	1.59	0.12	0	0.61	14.42	0	2.47	3.22	0.11	0.01	0.81	0	0.21	0.01	0	0.01	26.74
Europe	USSR	0	0	0	0.32	0	0	12.49	1.48	0.71	0	12.13	0.27	0.31	0	0.06	0	0.31	0	28.08
	E Europe	0	0	0	0.15	0	0	0.32	0.01	0.01	0	0.29	2.13	0.07	0	0	0	0	0	2.98
	W Europe	0.14	3.13	2.5	57.54	0	3.86	29.55	1.35	1.54	0.24	2.21	2.44	0.24	0.04	0	1.05	3.41	0.04	109.28
America	C Amr	0	0	0	0.67	0	0	0	0	0	0	0	0	0.43	0.16	0.07	0.16	0	0	1.49
	N Amr	1	1.69	4.42	38.84	0.07	7.01	33.49	35.11	43.4	2.55	2.45	0.35	4.89	26.87	5.76	36.4	11.18	0.05	255.53
	S Amr	0.91	0.08	1.42	9.74	0	0.39	15.41	1.09	2.65	0.23	0	0.54	1.43	0.37	0	35.48	0.36	0	70.1
Caribbean	Caribbean	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0.01
Oceania	Oceania	0.31	0	3.22	0.81	0	0	46.19	1.78	26.96	1.2	0	0	0.56	0	0	0.13	0	2.78	83.94
Imported Virtual Water (km3)		7.8	8.59	17.52	112.86	0.07	33.7	182.29	43.07	97.36	8.02	18.06	6.5	9.95	27.44	7.09	73.23	16.35	3.29	673.19

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Implications of virtual water concept on management of international water systems: Cases of two Asian international river basins

M. Nakayama

Introduction

Transboundary transfer of water resources has been planned in many places of the world. The “Interbasin Water Transfer” session at the Second World Water Forum concluded that in regions where water demand is still growing, transboundary water transfer will continue to be a viable option for meeting increasing needs (World Water Forum, 2000). However, in only limited number of cases, water resources have been transferred from one international river/lake basin to another. The Lesotho Highland Water Project (LHWP) is one of a few exceptional cases, where transboundary water transfer has taken place between Lesotho and South Africa since 1998.

The concept of “virtual water”, thus most broadly defined, as “water embedded in key water-intensive commodities”, is fairly new, appearing first in academia in the late 1990s. Case studies of “virtual water” trade are so far limited in number, due to the term’s recent entry into the academic and professional language. However, being an intuitively easily understandable and practical concept (rather than a theoretical model), it has been drawing increasing attention widely as an analytical tool to rethink the issue of water scarcity and water conflict.

Trade of water resources, either real or virtual, should give impacts on the relation of basin countries in an international water system. International water system in this context implies both traditional international river/lake system and “newly created” one by either by real or virtual trade of water resources.

The concept of Virtual Water is too new to have accumulated case studies by researchers. Following case studies are being carried out by the stewardship of the UNU, in collaboration with other research institutes. This paper summarizes the activities in these case studies.

Afghanistan in the Aral Sea basin

The Aral Sea basin extends over 690,000-sq. km., including Kazakhstan, Kyrghzstan, Tajikistan, Turkmenistan and Uzbekistan. A small portion of its headwater is located in Afghanistan, Iran and Chine. The basin is formed by two of the largest rivers of Central Asia - Amu Darya and Syr Darya - both fed by the snowmelt and glaciers from the mountains. The Amu Darya sources are mostly located in Tajikistan, with some watercourses originating in northeastern Afghanistan. The Syr Darya originates mainly in Kyrghyzstan. It runs across small portion of Tajikistan and Uzbekistan and through the Kazakh provinces of Chimkent and Kzyl-Orda.

In 1960, the Aral Sea was the fourth largest inland lake in the world. Since then, however, it has shrunk significantly because of nearly total cutoff of river inflow from the Amu Darya and Syr Darya as a result of heavy withdrawal for irrigation. By 1989 the sea level had fallen by 14.3 meters and the surface area had shrunk from 68,000-sq. km. to 37,000 sq. km. The salinity of the sea had increased to 2.8 times its 1960 level. The main issues relating to the Aral Sea basin area are the following: the reduction of the sea, the destruction of its aquatic ecosystem, the lowering of soil quality in the Aral Sea Basin, pollution of surface and groundwater of the delta draining into the Aral Sea, depressed economy and adverse health impact on the population due to lack of portable water and inadequate sanitation.

Of eight basin countries, five former Soviet Union countries have been considered major stakeholders. These nations have a mechanism, as a river basin organization, for discussion over the shared water resources. The mechanism however does not seem to be functioning well. In terms of working on the environmental disaster of the basin, which stems from the policy of large-scale irrigation development in 1950's through 1980's by the Soviet Union, few measures have been taken by these five countries to reduce water consumption for irrigation.

The new challenge these countries now face is political stabilization in the Afghanistan and (possibly) subsequent increasing consumption of water resources to increase agricultural production in the northern part of the country. The water in the Aral Sea is replenished by two major rivers. One of these, namely Amu Darya, has its source in high mountains in Tajikistan and Afghanistan. Any increase in water consumption within Afghanistan will lead to decrease of water availability in the downstream region.

The food production of Afghanistan in these days is nearly one-half of the same in late 1970's (JSCE, 2002). A lot of "virtual water" has been brought into Afghanistan either by food import or through food aid operation by the donor community. In case Afghanistan consumes more water in the Amu Darya basin towards food self-sufficiency, downstream countries will have much less water in the same river. What is worse, population of Afghanistan is supposed to increase by 100% in the coming two decades. It also implies drastic decrease of flow in the downstream area of the Amu Darya, provided Afghanistan aims at food self-sufficiency for the increasing population.

These trends of increasing water consumption in Afghanistan may lead to conflicts among basin countries. Apparently some measures should be taken to mitigate impacts of agricultural production expansion in Afghanistan. Such measures may include improvement in water use efficiency in the downstream area, change in economic structure of both upstream and downstream countries, etc. A new river basin organization, with participation of all the basin countries, should be established and be made functional as a mechanism to address issues over their shared water resources. Above all, tradeoffs between "real water" consumption (food production within the country) and "virtual water" consumption (import of food from abroad) in Afghanistan should be addressed from the viewpoint of security among basin countries.

Thailand and Vietnam in the Mekong river basin

The "Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin" was signed by plenipotentiaries from Cambodia, Laos, Thailand and Vietnam at Chiang Rai, Thailand, in April 1995. It provides principles for sustainable development, utilization, management and conservation of the water and related resources of the Mekong river basin, and institutional, financial and management issues relating to the mechanism of coordination between the member countries (MRC, 1996). The Agreement immediately established the Mekong River Commission, which replaced the former Mekong Committee established in 1957 by the same set of four riparian countries.

This new mechanism for the basin countries was the outcome of numerous discussions held among basin countries in early 1990's, which stemmed from conflicts between Thailand and Vietnam. The Mekong Committee adopted in January 1975 the Joint Declaration of Principles for Utilization of the Waters of the Mekong Basin (Mekong Committee, 1975a). "1975 Joint Declaration", which included 35 articles, defined the water resources of the mainstream as "a resources of common interest not subject to major unilateral appropriation by any riparian state without prior approval by the other basin states" in its Article 10 (Mekong Committee, 1975b). The Article 20 mentioned, "Extra-basin diversion of mainstream waters by a riparian state shall require the agreement of all basin states." Each basin country was thus in practice given the "veto power" over the conduct of another country regarding diversion of waters in the mainstream, regardless of the use, namely either within the basin or outside of the catchment.

In a workshop held by the Interim Mekong Committee in March 1991, a representative from Thailand mentioned "the principles enshrined in the 1975 Joint Declaration have been taken as the guidelines in the mutual co-operation between interested riparian states for already 16 years. It is high time now to review this Declaration in order to identify problems that it entails in practice." (Danvivathana, 1991). Thailand clearly wanted to have a new framework rather than "1975 Joint Declaration".

The reason why Thailand disliked the "1975 Joint Declaration" was because it then had a plan, named Kong-Chi-Moon project, to direct water from the mainstream of the Mekong River into its Northeastern region. Thailand thus wanted to avoid the "veto power" given to other basin countries per "1975 Joint Declaration". Vietnam objected to the Kong-Chi-Moon project, for it may reduce the flow in dry season and may cause intrusion of saline water into the Mekong Delta, the "rice bowl" of Vietnam. The position of Thailand was uncompromising. Thailand claimed to reserve the right to exploit the mainstream waters equal to the amount contributed by the tributaries in Thailand, which Thailand believed to be 12 to 16 per cent of the total flow (Weatherbee, 1997). This conflict was solved after nearly 5 years long of negotiations among basin countries with mediation by the UNDP (Nakayama, 1999).

This case should also be examined from the viewpoint of virtual water, so that following questions may be answered: (a) To what extent the export of virtual water by Thailand and Vietnam, in form of exporting agricultural products, gives impacts on relations of these countries in sharing water resources of the Mekong River? (b) How the economic structure of these countries may be changed in future to decrease the export of virtual water? (c) Is getting "real water" from the Mekong River the only viable solution for economic development of the Thailand's Northeastern region?

Conclusions

More than 200 international water systems exist in the world. About 50 to 60% of the global population resides within international water systems. Security issue of the international water systems is thus of great importance for many people in this world. This issue should be seen from "real water" and "virtual water" viewpoints.

Some existing policies should be re-examined. Attaining or improving food self-sufficiency by a basin country may lead to a conflict with other nations sharing in an international water system. Reliance on food aid by foreign countries, i.e. importing free "virtual water", may be seen as a mechanism to abate conflicts among basin countries. Tradeoffs between trading "real water" and "virtual water" should be examined before carrying out a large-scale transboundary water transfer scheme.

Acknowledgements

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Appendix I

Programme of the International Expert Meeting on Virtual Water Trade

IHE Delft, the Netherlands, 12-13 December 2002

Wednesday 11 December 2002

Arrival of participants

17.00 onward	Reception, registration and drinks – Room: Prinsenkamer
18.30 – 21.00	Dinner – Place: Restaurant of IHE

Thursday 12 December 2002
Room: A2

09.00 – 09.30	Reception, registration and coffee
09.30 – 09.45	Opening
09.45 – 11.00	Presentations & discussion
	Tony Allan - Virtual water eliminates water wars: water, food and trade
	Daniel Zimmer - The World Water Council Virtual Water Project
	Daniel Renault – Principles in assessing the value of virtual water in food
	Detlef van Vuuren - Analogy between ecological footprint and virtual water concept
11.00 – 11.15	Coffee / tea break
11.15 – 12.45	Presentations & discussion
	Arjen Hoekstra - Virtual water flows between nations in relation to international crop trade
	Hong Yang - Analysis of water scarcity-induced cereal grain import
	Huub Savenije - The importance of green water in studies of virtual water trade
	Jeroen Warner - Virtual water trade as an instrument for conflict prevention
12.45 – 13.45	Lunch
13.45 – 15.00	Presentations & discussion: Cases from Africa
	Dennis Wichelns - Virtual water trade in Egypt
	Anton Earle - The virtual water trade amongst countries of the SADC
	Richard Meissner - Virtual water trade and regional food security in Southern Africa
15.00 – 15.30	Coffee / tea break
15.30 – 16.30	Break-out sessions on aims, set-up and targeted results of the Special Session on Virtual Water Trade at the 3rd World Water Forum
16.30 – 17.00	Plenary presentation and discussion of results break-out sessions
17.00	Drinks – Room: Prinsenkamer
18.30	Dinner – Place: Restaurant of IHE

20.00 – 21.30	Special meeting on WWC's Virtual Water Project

Friday 13 December 2002
Room: A2

09.00 – 11.00	Presentations & discussion: Cases from the Middle East and Japan
	Munther Haddadin - Exogenous water: A conduit to globalization of water resources
	Mikiyasu Nakayama - Implications of the virtual water concept on the management of international water systems - cases of two Asian river basins
	Taikan Oki - Virtual water trade Japan
	Katsuhiko Mori - Virtual water trade in global governance
11.00 – 11.15	Coffee / tea break
11.15 – 12.45	Presentations & discussion
	Ellen Marie Douglas - Preliminary results: Virtual water and unsustainable irrigation use
	Ashok Chapagain - Virtual water trade related to international trade of livestock products
	Gordon Young - Virtual water in the context of the World Water Assessment Programme
	Kumi Furuyashiki - Planning of virtual water studies at the United Nations University
	Holger Hoff - Future research needs on virtual water
12.45 – 13.45	Lunch
13.45 – 15.15	Break-out sessions on statements and policy recommendations to be brough into the Third World Water Forum
15.15 – 15.45	Plenary presentation and discussion of results break-out sessions
15.45 – 16.00	Closure by **Janos Bogardi**
16.00 – 17.00	Drinks – Room: Prinsenkamer

Appendix II

List of participants of the International Expert Meeting on Virtual Water Trade

Surname	**Name**	**Institute**	**Country**
Allan	Tony	SOAS, University of London	UK
Bogardi	Janos	UNESCO	France
Bresser	Ton	RIVM	Netherlands
Chapagain	Ashok	UNESCO-IHE	Netherlands
De Fraiture	Charlotte	IWMI	Sri Lanka
Douglas	Ellen Marie	University of New Hampshire	USA
Earle	Anton	University of Pretoria	South Africa
Furuyashiki	Kumi	United Nations University	Japan
Haddadin	Munther	Ex-Minister of Water	Jordan
Hoekstra	Arjen	UNESCO-IHE Institute for Water Education	Netherlands
Hoff	Holger	Potsdam Institute for Climate Impact Research (PIK)	Germany
Kram	Tom	RIVM	Netherlands
Limbrunner	James	Tufts University	USA
Meissner	Richard	University of Pretoria	South Africa
Mori	Katsuhiko	Yokohama City University	Japan
Nakayama	Mikiyasu	University of Tokyo	Japan
Oki	Taikan	University of Tokyo	Japan
Renault	Daniel	FAO	France
Savenije	Huub	UNESCO-IHE Institute for Water Education	Netherlands
Strigel	Gerhard	IHP-OHP Sekretariat	Germany
Van Hofwegen	Paul	UNESCO-IHE Institute for Water Education	Netherlands
Van Vuuren	Detlef	RIVM	Netherlands
Verweij	Wilko	RIVM	Netherlands
Warner	Jeroen	Wageningen University and Research Centre (WUR)	Netherlands
Wichelns	Dennis	California State University	USA
Yang	Hong	EAWAG	Switzerland
Young	Gordon J.	World Water Assessment Programme	France
Zimmer	Daniel	World Water Council	France