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September 2005

Saving water through global trade

Value of Water

Research Report Series No. 17

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Contents

Summary

Many nations save domestic water resources by importing water-intensive products and exporting commodities that are less water intensive. National water saving through the import of a product can imply saving water at a global level if the flow is from sites with high to sites with low water productivity. The report analyses the consequences of international virtual water flows on the global and national water budgets. The assessment shows that the total amount of water that would have been required in the importing countries if all imported agricultural products would have been produced domestically is 1605 Gm^3/yr. These products are however being produced with only 1253 Gm^3/yr in the exporting countries, saving global water resources by 352 Gm^3/yr. This saving is 28 per cent of the international virtual water flows related to the trade of agricultural products and 6 per cent of the global water use in agriculture. National policy makers are however not interested in global water savings but in the status of national water resources. Egypt imports wheat and in doing so saves 3.6 Gm^3/yr of its national water resources. Water use for producing export commodities can be beneficial, as for instance in Cote d'Ivoire, Ghana and Brazil, where the use of green water resources (mainly through rain-fed agriculture) for the production of stimulant crops for export has a positive economic impact on the national economy. However, export of 28 Gm^3/yr of national water from Thailand related to rice export is at the cost of additional pressure on its blue water resources. Importing a product which has a relatively high ratio of green to blue virtual water content saves global blue water resources that generally have a higher opportunity cost than green water.

1. Introduction

The most direct positive effect of virtual water trade is the water savings it generates in the countries or the regions that import the products. This effect has been widely discussed in virtual water studies since the nineties (Allan, 1999; Hoekstra, 2003). These national water savings are equal to the import volumes multiplied by the volumes of water that would have been required to produce the commodities domestically. However, virtual water trade does not only generate water savings for importing countries, it also means water ‘losses’ for the exporting countries (in the sense that the water cannot be used anymore for other purposes in the exporting countries). The global net effect of virtual water trade between two nations will depend on the actual water volume used in the exporting country in comparison to the water volume that would have been required to produce a commodity in the importing country. There will be net water saving, if the trade is from countries with relatively high water productivity (i.e. commodities have a low virtual water content) to countries with low water productivity (commodities with a high virtual water content). There can be net additional consumption of water if the transfer is from low to high productive sites. The saving can also be realised with transfer of products from low to high productive periods by storage of food, which can be a more efficient and more environmentally friendly way of bridging the dry periods than building large dams for temporary water storage (Renault, 2003).

Virtual water trade between nations is one means of increasing the efficiency of water use in the world. As Hoekstra and Hung (2002; 2005) argue, there are three levels of water use efficiency. At a local level, that of the water user, water use efficiency can be increased by charging prices based on full marginal cost, stimulating water-saving technology, and creating awareness among the water users on the detrimental impacts of water abstractions. At the catchment or river basin level, water use efficiency can be enhanced by re-allocating water to those purposes with the highest marginal benefits. Finally, at the global level, water use efficiency can be increased if nations use their comparative advantage or disadvantage in terms of water availability to encourage or discourage the use of domestic water resources for producing export commodities (respectively stimulate export or import of virtual water). Whereas much research efforts have been dedicated to study water use efficiency at the local and river basin level, little efforts have been done to analyse water use efficiency at global level.

According to the theory of comparative advantage, nations can gain from trade if they concentrate or specialize in the production of goods and services for which they have a comparative advantage, while importing goods and services for which they have a comparative disadvantage (Wichelns, 2001; 2004). The pros and cons of the virtual water trade should be weighed including the opportunity cost of the associated water. Some trade flows may be more beneficial than others purely because of the higher opportunity cost of the water being saved. It is relevant for instance to look whether water saved is *blue* or *green* water. Green water is the productive use of rainfall in crop production, which, in general, has a lower opportunity cost compared to the blue water use (i.e. irrigation).

The average global volume of virtual water flows related to the international trade in agricultural products was 1263 Gm^3/yr in the period 1997-2001 (Chapagain and Hoekstra, 2004). This estimate is based on the virtual water content of the products in the exporting countries. It would be interesting to see the volume of virtual water traded internationally based on the virtual water content of the products in the importing countries. Zimmer and Renault (2003) estimated this as 1340 Gm^3 /yr related to the international trade in crop and livestock products in the year 2000. These studies only present a partial view of the global or national savings.

An estimate of global virtual water trade and resulting global water saving was done by Oki *et al*. (2003) and Oki and Kanae (2004). They estimated the global sum of virtual water exports on the basis of the virtual water content of the products in the exporting countries (683 Gm^3/yr) and the global sum of virtual water imports on the basis of the virtual water content of the products in the importing countries (1138 Gm^3/yr). This saves 455 Gm^3/yr as a result of food trade. Their study is severely limited with respect to the methodology followed in calculating the virtual water content of a product. First, they have assumed a constant global average crop water requirement throughout the world, being 15 mm/day for rice and 4 mm/day for maize, wheat and barley. Thus the climatic factor, which plays a major role in the crop water requirement of a crop, is completely neglected. Secondly, they did not take into account the role of the crop coefficient, which is the major limiting factor determining the evaporation from a crop at different stages of crop growth. The global virtual water flows and the resulting water savings as calculated in these studies are limited to the international trade of four major crops (maize, wheat, rice and barley) only.

The purpose of this study is to quantify and analyse the global and national water savings for the period 1997-2001 with proper accounting of climate, yield, and cropping pattern per crop per country. The study covers the international trade of all major crop and livestock products.

2. Methodology

The virtual water content of a product is calculated using the methodology as developed by Hoekstra and Hung (2002; 2005) and Chapagain and Hoekstra (2003; 2004). First the virtual water content (m^3/ton) of the primary crop is calculated based on crop water requirement and yield in the producing country. The crop water requirement is calculated using the methodology developed by FAO (Allen *et al.*, 1998). The calculation is done using the climate data of the producing country and the specific cropping pattern of each crop per country. The virtual water content (m^3/ton) of live animals has been calculated based on the virtual water content of their feed and the volumes of drinking and service water consumed during their lifetime. The virtual water content of processed products is calculated based on product fractions (ton of crop product obtained per ton of primary crop or live animal) and value fractions (the market value of one crop or livestock product divided by the aggregated market value of all products derived from one primary crop or live animal). The product fractions have been taken from the commodity trees in FAO (2003). The value fractions have been calculated based on the market prices of the various products. The global average market prices of the different products for the period 1997-2001 have been calculated using trade data from the International Trade Centre (ITC, 2004).

The national water saving ΔS_n (m^3/yr) of a country n_i as a result of trade of product p is:

$$\Delta S_n[n_i, p] = V[n_i, p] \times I[n_i, p] - V[n_i, p] \times E[n_i, p] \tag{1}$$

where V is the virtual water content (m^3/ton) of the product p in country n_i, I the amount of product p imported (ton/yr) and E is the amount of product exported (ton/yr). Obviously, ΔS_n can have a negative sign, which means a net water loss instead of a saving.

The global water saving ΔS_g (m^3/yr) through the trade of a product p from an exporting country n_e to an importing country n_i, is:

$$\Delta S_g[n_e, n_i, p] = T[n_e, n_i, p] \times (V[n_i, p] - V[n_e, p]) \tag{2}$$

where T is the amount of trade (ton/yr) between the two countries. The global saving is thus obtained as the difference between the water productivities of the trading partners. The total global water saving can be obtained by summing up the global savings of all trades ΔS_g. By definition, the total global water saving is also equal to the sum of the national savings of all countries ΔS_n.

The case of global water saving is illustrated with an example of the import of husked rice in Mexico from the USA in Figure 2.1. The case of global water loss is shown with an example of export of broken rice from Thailand to Indonesia in Figure 2.2. For the computation of the total water saving that is made by international trade of agricultural products, the calculation has been carried out for 285 crop products and 123 livestock products as reported in the database PC-TAS (ITC, 2004) which covers international trade between 243 countries for 1997-2001.

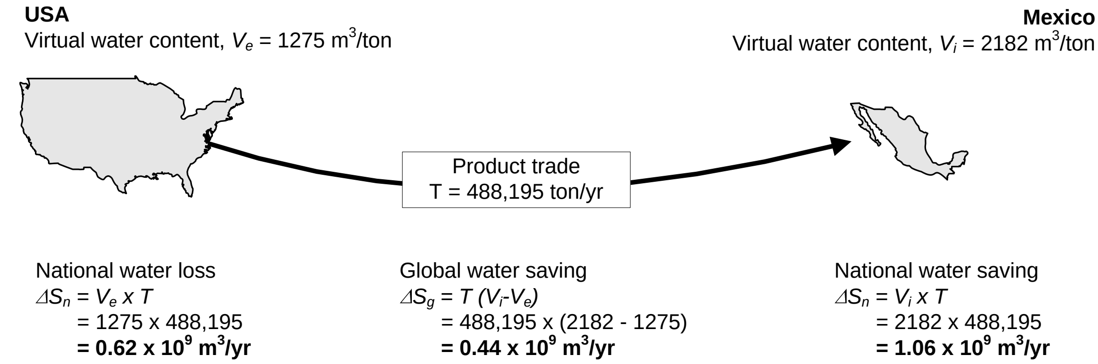

Figure 2.1. An example of global water saving with the import of husked rice in Mexico from USA.

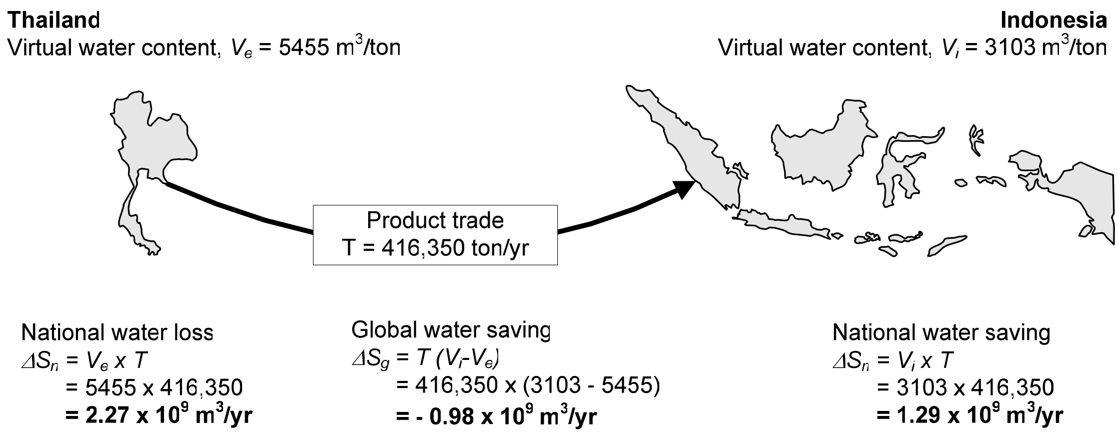

Figure 2.2. An example of global water loss with the import of broken rice in Indonesia from Thailand.

3. National water savings

A large number of countries are saving their national water resources with the international trade of agricultural products. Japan saves 94 Gm^3/yr from its domestic water resources, Mexico 65 Gm^3/yr, Italy 59 Gm^3/yr, China 56 Gm^3/yr and Algeria 45 Gm^3/yr. The global picture of national savings is presented in Figure 3.1. The water savings shown in the figure are net water savings. A net national water saving is the result of a gross water saving and a gross water loss (Appendix I). The driving forces behind international trade of water-intensive products can be water scarcity in the importing countries, but often other factors such as scarcity of fertile land or other resources play a decisive role (Yang *et al*., 2003). As a result, realised national water savings can only partially be explained through national water scarcity.

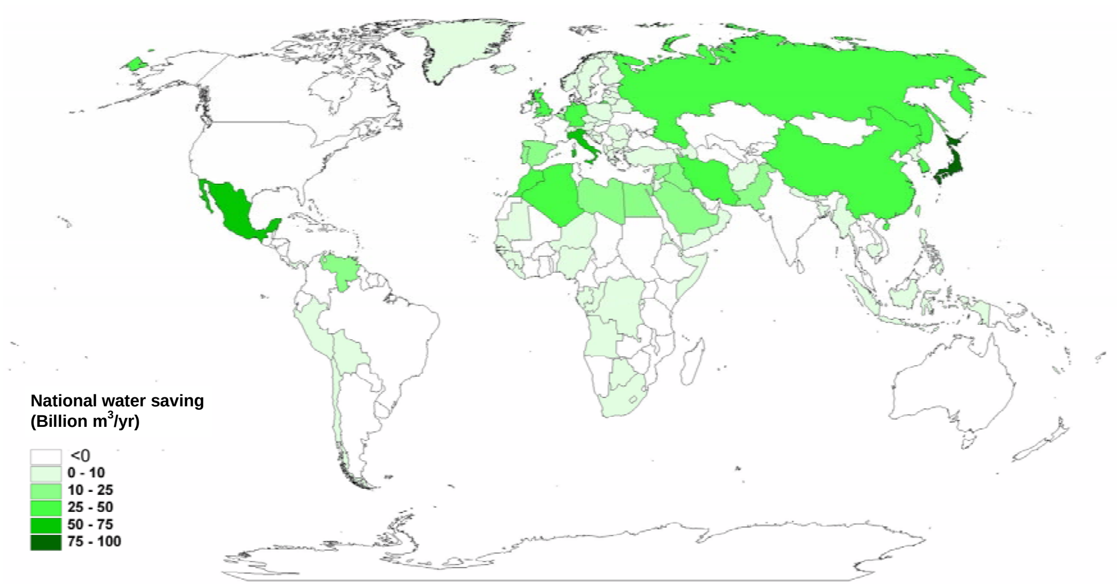

Figure 3.1. National water savings related to international trade of agricultural products. Period 1997-2001.

The national water saving has different implications per country. Though Germany saves 34 Gm^3/yr, it may be less important from a national policy making perspective because the major products behind the saving are stimulant crops (tea, coffee and cocoa) which Germany would otherwise not produce itself. If the import of stimulants is reduced, it may not create any additional pressure on the water resources in Germany. However, for Morocco, where import of cereal crop products is the largest national water saver, shifting from import to domestic production would create an additional pressure of 21 Gm^3/yr on its national water resources. The nations that save most water through international trade of agricultural products and the main products behind the savings are presented in Table 3.1.

For an importing country it is not relevant whether products are consuming green or blue water in the exporting country. The importing country is more interested to see what volume and kind of water is being saved from its own resources by the import. And it is further important to see whether the water thus saved has higher marginal benefits than the additional cost to import these products.

Table 3.1. Nations with the largest net water saving as a result of international trade of agricultural products. Period 1997-2001.

Countries	Net national water saving (Gm^3/yr)	Major partners (Gm^3/yr)	Major product categories (Gm^3/yr)
Japan	94	USA (48.9), Australia (9.6), Canada (5.4), Brazil (3.8), China (2.6)	Cereal crops (38.7), oil-bearing crops (23.2), livestock (16.1), stimulants (9.2)
Mexico	65	USA (54.0), Canada (5.1)	Livestock (31.0), oil-bearing crops (20.5), cereal crops (19.3)
Italy	59	France (14.6), Germany (6.0), Brazil (5.4), Netherlands (4.4), Argentina (3.1), Spain (3.1)	Livestock (23.2), cereal crops (15.2), oil-bearing crops (12.9), stimulant (8.1)
China	56	USA (17.4), Brazil (8.3), Argentina (8.3), Canada (3.6), Italy (3.4), Australia (3.2), Thailand (2.6)	Livestock (27.5), oil-bearing crops (32.6)
Algeria	45	Canada (10.8), USA (7.6), France (7.1), Germany (4.0), Argentina (1.6)	Cereal crops (33.7), oil-bearing crops (4.0), livestock (3.4)
Russian Fed.	41	Kazakhstan (5.2), Germany (4.4), USA (4.1), Ukraine (3.4), Brazil (3.3), Cuba (2.4), France (1.9), Netherlands (1.9)	Livestock (15.2), cereal crops (7.1), sugar (6.9), oil-bearing crops (4.3), stimulant (3.8), fruits (2.3)
Iran	37	Brazil (8.3), Argentina (8.1), Canada (7.7), Australia (6.0), Thailand (2.2), France (2.0)	Cereal crops (22.5), oil-bearing crops (15.1), sugar (1.6)
Germany	34	Brazil (8.3), Cote d'Ivoire (5.3), Netherlands (5.0), USA (4.2), Indonesia (3.3), Argentina (2.2), Colombia (2.1)	Stimulants (21.8), oil-bearing crops (15.0), fruits(3.4), nuts (2.3)
Korea Rep.	34	USA (15.6), Australia (3.6), Brazil (2.2), China (1.5), India (1.4), Malaysia (1.2), Argentina (1.1)	Oil-bearing crops (14.3), cereal crops (12.8), livestock (2.3), sugar (1.9), stimulants (1.5)
UK	33	Netherlands (5.3), France (3.7), Brazil (2.8), Ghana (1.9), USA (1.8), Cote d'Ivoire (1.5), Argentina (1.4)	Oil-bearing crops (10.1), stimulants (9.5), livestock (5.2)
Morocco	27	USA (7.8), France (6.4), Argentina (3.3), Canada (2.2), Brazil (1.2), Turkey (0.8), UK (0.8)	Cereal crops (20.9), oil-bearing crops (4.4)

As an example, Figure 3.2 shows the national water saving of Egypt as a result of the import of wheat. In Egypt, the mean rainfall is only 18 mm/yr. Almost all agriculture in Egypt is irrigated. At present, Egypt and Sudan base their water resources plan on the agreed division of water by the 1959 Nile water agreement between Sudan and Egypt. However, future developments in upstream countries will have to be taken into account. Disputes over the distribution of water of the Nile could become a potential source of conflict and contention. The expansion of irrigation in the basin will require basin-wide cooperation in the management of water resources to meet increasing demands and to face the associated environmental consequences. In this context, the import of wheat in Egypt is contributing to national water saving of 3.6 Gm^3/yr which is about seven percent of the total volume of water Egypt is entitled to according to the 1959 agreement. The national saving is made with the investment of foreign exchange of 593 million US$/yr (ITC, 2004). Hence, from an economic point of view, the opportunity cost of the resources being saved (such as land, water and labour) should be more or at least equal to the price paid for it. If the opportunity cost of land and labour approaches zero, the opportunity cost of water being saved should be more than 0.17 US$/$m^3$. But the import of wheat in Egypt should be assessed including other factors of production such as land and labour. In Egypt fertile land is also a major scarce resource. The pressure to increase the land area with reclamation is released to some extent by the wheat import but on the other hand the import is made at the cost of employment lost. Greenaway *et al.* (1994) and Wichelns (2001) have shown that the production of wheat has a comparative disadvantage in Egypt. As the saving is completely in blue water, the marginal utility of the saved water may justify the import economically.

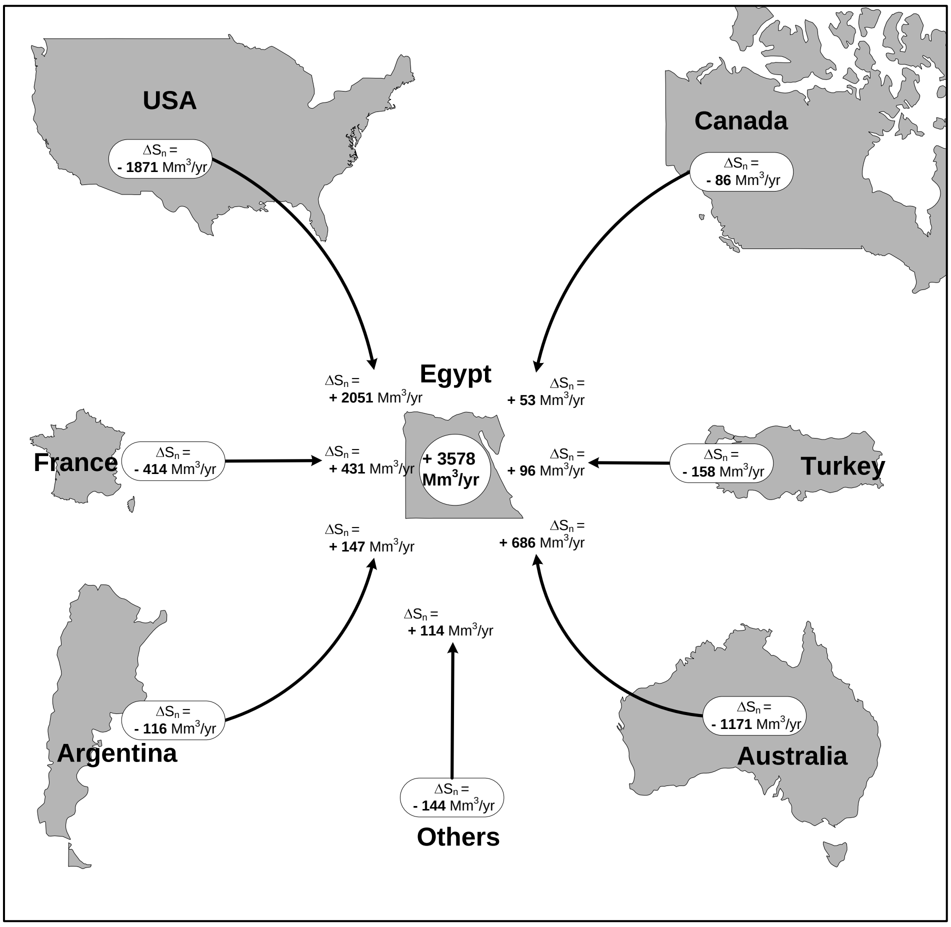

Figure 3.2. National water saving related to the net wheat import of Egypt. Period 1997-2001.

4. National water losses

Whereas import of agricultural products implies that national water resources are saved, export of agricultural products entails that national water resources are lost. The term 'national water loss' is used in this paper to refer to the fact that water used for producing commodities that are consumed by people in other countries is not available anymore for in-country purposes. The term 'water loss' is used here as the opposite of 'water saving'. The terms 'loss' and 'saving' are not to be interpreted in terms of economic loss or saving, but in a physical manner (refer to Equation 1). Calculated national water savings and losses become valued positive or negative in an economic sense depending on the context. Water losses as defined here are negative in economic sense only if the benefit in terms of foreign earning does not outweigh the costs in terms of opportunity cost and negative externalities left at the site of production.

The nations with the largest net water loss are the USA (92 Gm^3/yr), Australia (57 Gm^3/yr), Argentina (47 Gm^3/yr), Canada (43 Gm^3/yr), Brazil (36 Gm^3/yr) and Thailand (26 Gm^3/yr) (Appendix I). Figure 4.1 shows the water losses of all countries that have a net water loss due to the production for export. The list of nations with the largest net water loss through the international trade of agricultural products is presented in Table 4.1.

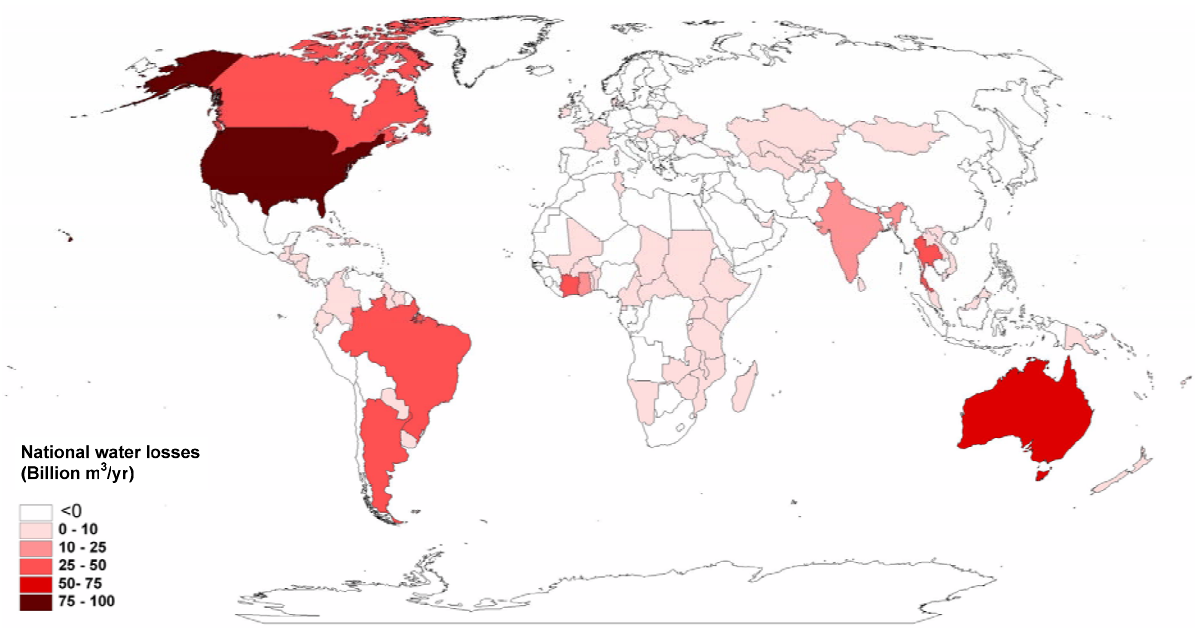

Figure 4.1. National water losses related to international trade of agricultural products. Period 1997-2001.

The main products behind the national water loss from the USA are oil-bearing crops and cereal crops. These products are partly produced rain-fed and partly irrigated. However the loss from Cote d'Ivoire and Ghana is mainly from the export of stimulants, which are almost entirely rain-fed. The use of green water has no major competition with other uses in these countries. This type of loss to the national water resources is unlikely to be questionable from an economic perspective, because the opportunity costs of this water are low. The concern is limited to the environmental impacts, which are generally not included in the price of the export products.

Table 4.1. Nations with the largest net water loss as a result of international trade of agricultural products. Period 1997-2001.

Countries	Net national water loss (Gm^3/yr)	Major partners (Gm^3/yr)	Major product categories (Gm^3/yr)
USA	92	Japan (29.2), Mexico (26.8), China (14.1), Korea Rep (10.1), Taiwan (8.4), Egypt (3.8), Spain (3.7)	Oil-bearing crops (65.2), cereal crops (45.4), livestock (7.8)
Australia	57	Japan (13.7), China (6.0), USA (5.7), Indonesia (4.7), Korea Rep (3.9), Iran (3.3)	Cereal crops (23.1), livestock (24.3), oil-bearing crops (6.8), sugar (4.3)
Argentina	47	Brazil (6.7), China (3.7), Spain (2.4), Netherlands (2.2), Italy (2.1), USA (2.0), Iran (1.9)	Oil-bearing crops (29.9), cereal crops (12.8), livestock (3.7)
Canada	43	USA (12.4), Japan (7.9), China (5.2), Iran (3.7), Mexico (3.4), Algeria (2.1)	Cereal crops (29.3), livestock (12.3), oil-bearing crops (9.6)
Brazil	36	Germany (5.8), USA (5.3), China (4.5), Italy (4.2), France (4.2), Netherlands (3.9), Russian Fed (2.8)	Oil-bearing crops (17.7), stimulants (15.8), sugar (9.0), livestock (9.3)
Cote d'Ivoire	32	Netherlands (5.7), France (4.7), USA (4.5), Germany (4.1), Italy (1.7), Spain (1.5), Algeria (1.4)	Stimulants (32.9), oil-bearing crops (1.5)
Thailand	26	Indonesia (4.7), China (4.4), Iran (2.6), Malaysia (2.5), Japan (2.3), Senegal (1.8), Nigeria (1.7)	Cereal crops (23.6), Sugar (5.1), roots and tuber (2.5)
Ghana	17	Netherlands (3.6), UK (3.3), Germany (1.7), Japan (1.6), USA (1.3), France (1.0)	Stimulants (19.1)
India	13	China (2.4), Saudi Arabia (2.0), Korea Rep (1.8), Japan (1.6), Russian Fed (1.3), France (1.3), USA (1.3)	Cereal crops (6.1), stimulants (3.2), livestock (3.0), oil-bearing crops (1.8)
France	9	Italy (6.4), Belgium-Luxembourg (3.8), UK (2.8), Germany (2.1), Greece (1.6), Algeria (1.4), Morocco (1.1)	Cereal crops (21.9), sugar (4.6), livestock (4.2)
Vietnam	8	Indonesia (2.3), Philippines (1.7), Ghana (0.4), USA (0.4), Germany (0.4), Senegal (0.4), Singapore (0.4)	Cereal crops (6.8), stimulants (2.7)

The national water losses from France, Vietnam and Thailand are mainly the result of cereal crop products. Particularly the example of rice export from Thailand is interesting from blue water and opportunity cost perspective (Figure 4.2). Thailand exports 27.8 Gm^3/yr of water in the form of rice. The monetary equivalent of rice export is 1556 million US$/yr (ITC, 2004). Hence, from the loss of its national water, Thailand is generating foreign exchange of 0.06 US$/$m^3$. The water loss is partly from blue water resources and partly from green water resources. As rice cultivation in Thailand is done during the rainy season, the share of green water is quite considerable in the virtual water content of the rice. Here, one needs to remember that the benefits of rice export should be attributed to all the resources consumed in the production process such as water, land and labour. If the contribution of rainfall is 50% to the total evaporative demand of the crop, and if other resources have zero opportunity cost (which is not the case) the opportunity cost of rice export from Thailand approaches 0.12 US$/$m^3$ of blue water. Though it is a crude estimation of opportunity cost of rice export, it indicates that the volume of national water loss could have produced higher economic benefits to the nation.

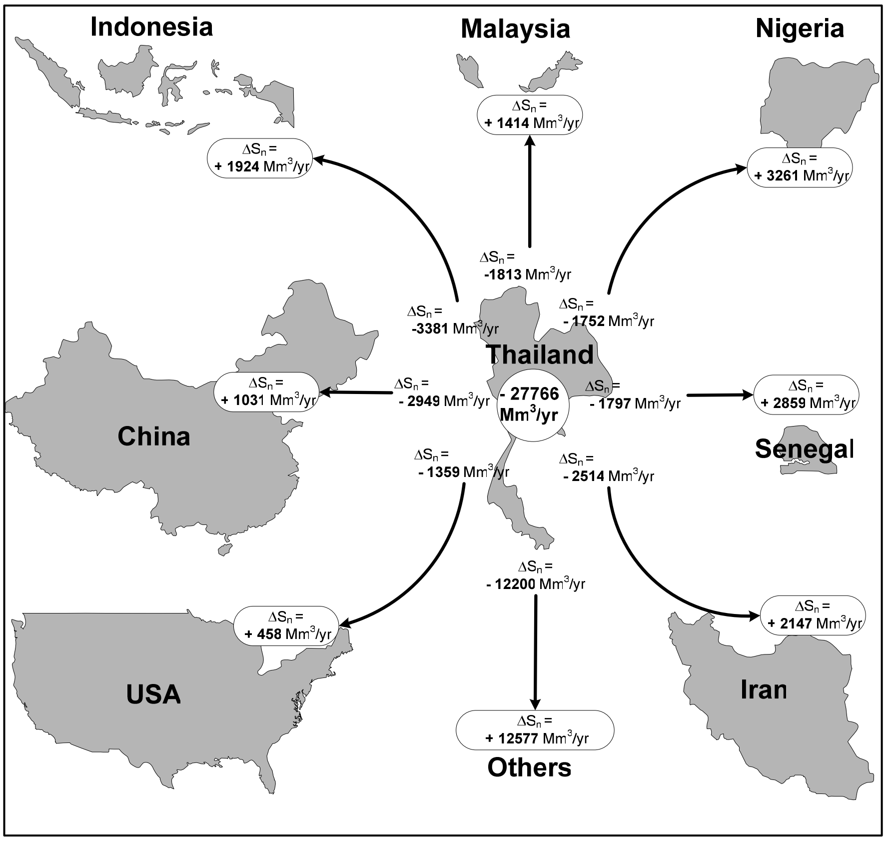

Figure 4.2. National water loss related to the net rice export of Thailand. Period 1997-2001.

5. Global water savings

Considering the international trade flows between all major countries of the world and looking at the major agricultural products being traded (285 crop products and 123 livestock products), it has been calculated that the global water saving by trade in agricultural products is 352 Gm^3/yr (Table 5.1). This volume equals 28% of the international virtual water flows related to agricultural product trade and 6% of the global volume of water used for agricultural production (which is 6391 Gm^3/yr, see Chapagain and Hoekstra, 2004). The trade flows that save more than 0.5 Gm^3/yr are shown in Figure 5.1. The trade flows between USA-Japan and USA-Mexico are the biggest global water savers. The contribution of different product groups to the total global water saving is presented in Figure 5.2. Cereal crop products form the largest group responsible for the total global water saving, with a saving of 222 Gm^3/yr, followed by oil-bearing crops (68 Gm^3/yr, mainly soybeans) and livestock products (45 Gm^3/yr). The cereal group is composed of wheat (103 Gm^3/yr), maize (68 Gm^3/yr), rice (21 Gm^3/yr), barley (21 Gm^3/yr), and others (9 Gm^3/yr).

Table 5.1. Global virtual water flows and water savings. Period 1997-2001.

	Related to trade of crop products (Gm^3/yr)	Related to trade of livestock products (Gm^3/yr)	Total (Gm^3/yr)
Global sum of virtual water exports, assessed on the basis of the virtual water content of the products in the exporting countries (Gm$^{3/}$yr)	979	275	1254
Global sum of virtual water imports, assessed on the basis of the virtual water content of products if produced in the importing countries (Gm$^{3/}$yr)	1286	320	1646
Global water saving (Gm$^{3/}$yr)	307	45	352
Saving compared to the sum of international virtual water flows (%)	34%	16%	30%
Saving compared to the global water use for agricultural products (%)	5.3%	0.7%	6%

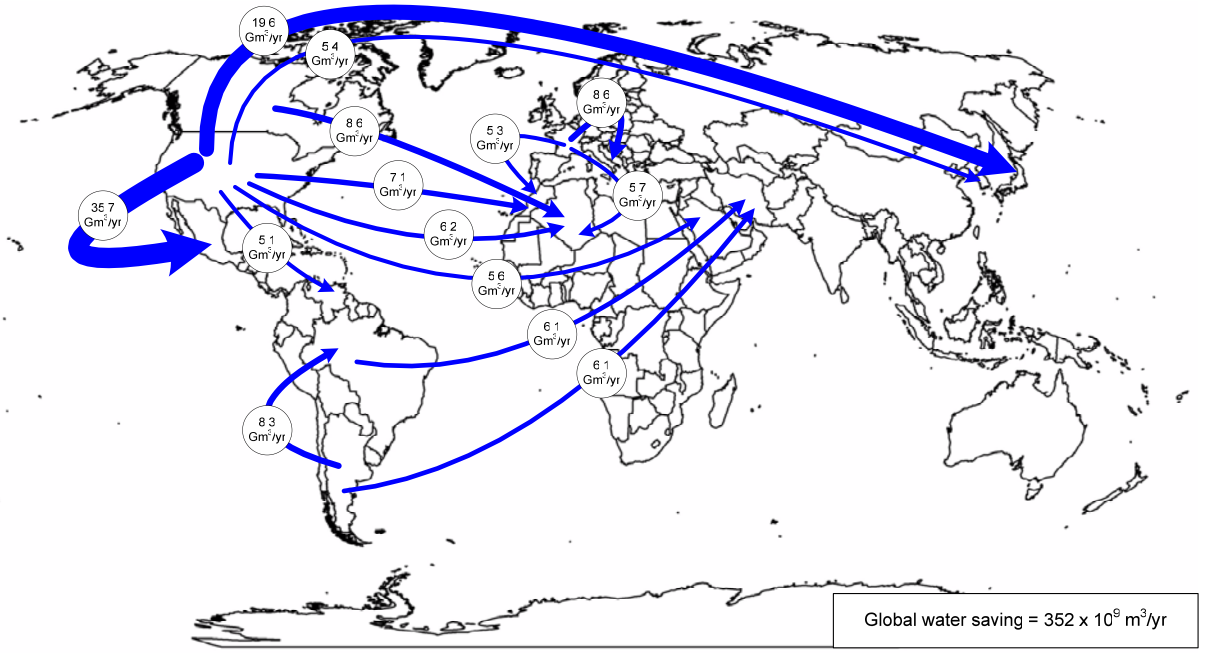

Figure 5.1. Global water savings (>5.0 Gm^3/yr) associated with international trade of agricultural products. Period 1997-2001.

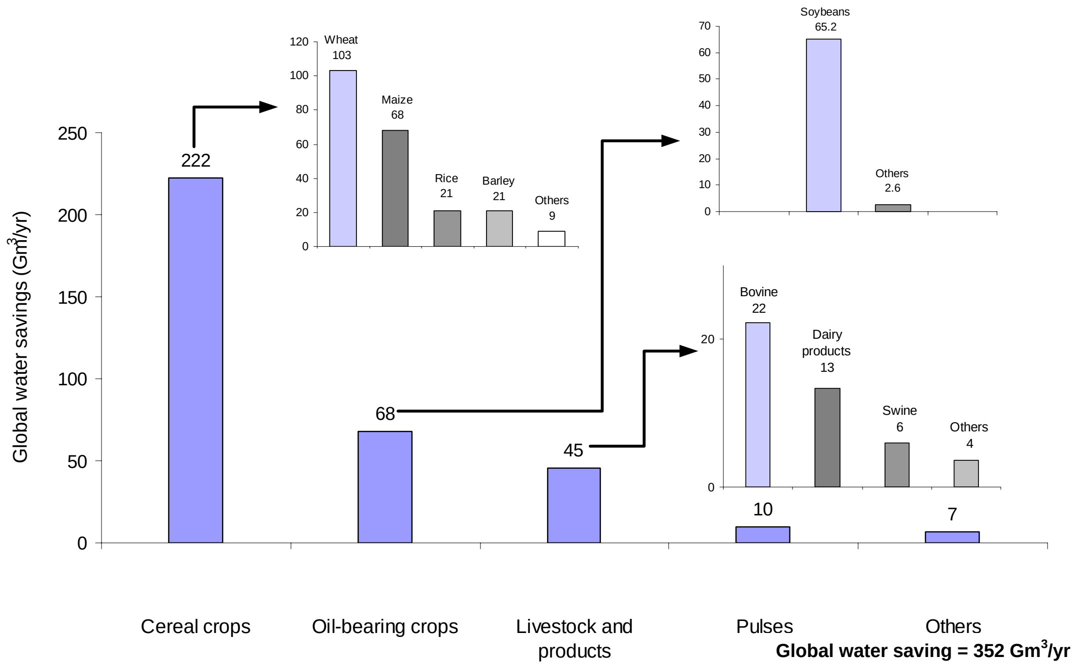

Figure 5.2. Global water savings (Gm^3/yr) per traded product category. Period 1997-2001.

The largest global water savings by wheat trade are occurring as a result of wheat import in the Middle East and North African from Western Europe and North America. Figure 5.3 shows the wheat trade flows saving more than 2 Gm^3 of water per year. Maize imports in Japan alone are responsible for 15 Gm^3/yr of global water saving. The global saving of water as a result of maize trade is mainly from the export of maize from USA. Figure 5.4 shows the maize trade flows saving more than 1 Gm^3/yr. Figure 5.5 shows the global water savings above 0.5 Gm^3/yr as a result of rice trade. As the production is more favourable (climate and culture) in South-east Asia, the largest savings are from the export from this region to the Middle East and West Africa. The major saving through the trade of rice is between Thailand-Iraq, Thailand-Nigeria, Syria-Nigeria, and China-Indonesia.

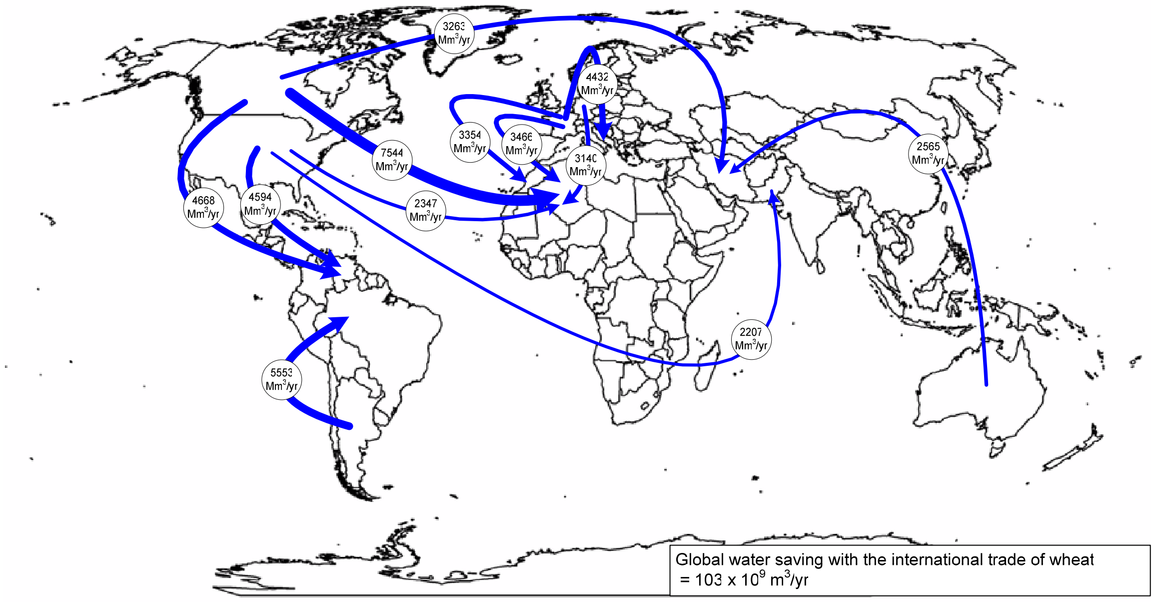

Figure 5.3. Global water savings (>2.0 Gm3/yr) associated with the international trade of wheat. Period 1997-2001.

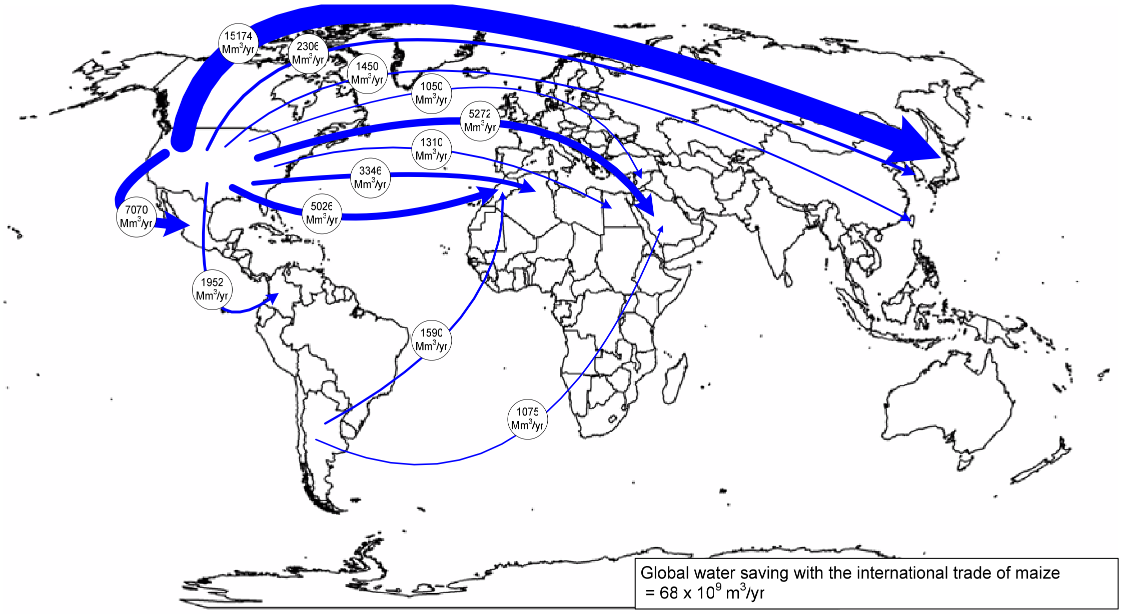

Figure 5.4. Global water savings (>1.0 Gm3/yr) associated with the international trade of maize. Period 1997-2001.

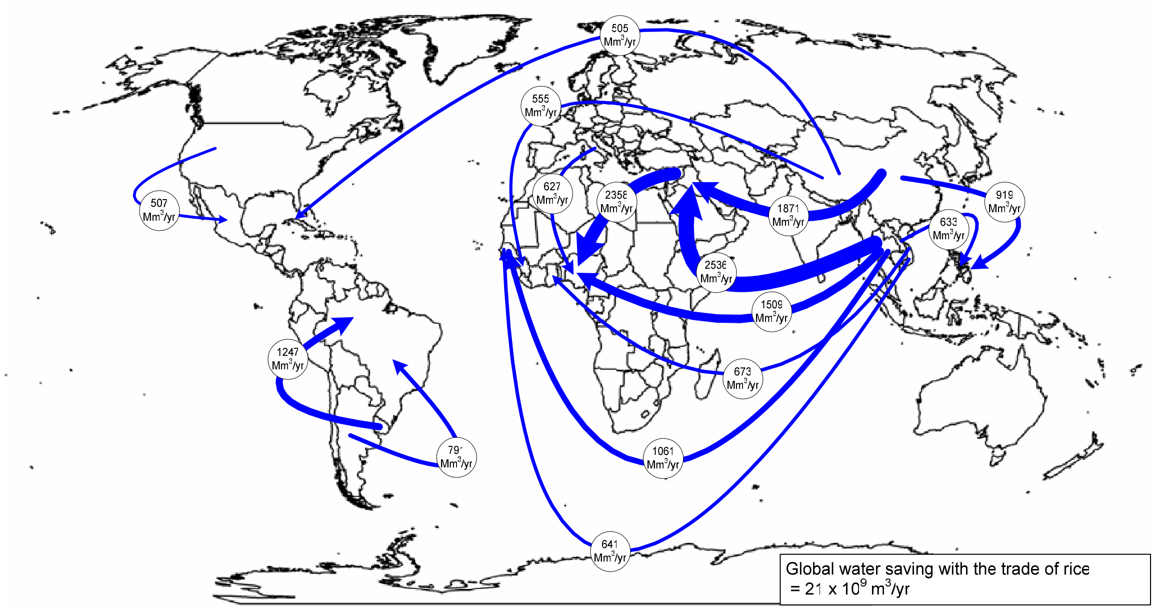

Figure 5.5. Global water savings (>0.5 Gm3/yr) associated with the international trade of rice. Period 1997-2001.

Considering the import of wheat in Egypt, one can see that this contributes to global water saving in some cases and global water loss in other cases (Figure 3.2). The import from USA, France and Argentina is globally saving water by 0.23 Gm^3/yr, whereas the import of wheat from Canada, Turkey and Australia results in a global water loss of 0.58 Gm^3/yr. Though Egypt's import of wheat saves national water resources by 3.6 Gm^3/yr, it results in a net global water loss of 0.4 Gm^3/yr. The crop water requirement in Egypt is relatively high compared to its trading partners, but this is partially compensated by a relatively high wheat yield, which is more than twice the global average (Table 5.2). As a result, water productivity (water use per unit of product) in wheat production in Egypt is higher than in Canada, Turkey and Australia. However, wheat production in Egypt is using scarce blue water resources and the partner countries are making use of the effective rainfall (green water). The net global water loss related to the wheat export from Canada etc. to Egypt results from the fact that the volume of *blue* water resources that would have been required in Egypt to produce domestically is smaller than the volume of *green* water resources actually used in Canada etc. Blue and green water resources fundamentally differ in terms of possible application and thus opportunity cost. For further analysis and interpretation of figures on global water savings or losses it is thus important to split up these figures into a blue and green water component.

Table 5.2. Crop water requirements, crop yields and the virtual water content of wheat in Egypt and its major trade partners. Period 1997-2001.

	Crop water requirement (mm/crop period)	Wheat yield (ton/ha)	Virtual water content (m^3/ton)
Argentina	179	2.4	738
Australia	309	1.9	1588
Canada	339	2.3	1491
Egypt	570	6.1	930
France	630	7.0	895
Turkey	319	2.1	1531
USA	237	2.8	849
Global average		2.7	1334

A second example elaborated here is the trade of maize from the USA to Japan. The global water saving from this trade is 15.4 Gm^3/yr. The evaporative demand of maize in Japan (367 mm/crop period) is comparable with that in the USA (411 mm/crop period), but the crop yield in the USA (8.4 ton/ha) is significantly higher than in Japan (2.5 ton/ha), so that the virtual water content of maize in Japan is 3 times higher than in the USA. Saving domestic water resources is not the only positive factor for Japan. If Japan would like to grow the quantity of maize which is now imported from the USA, it would require 6 million hectare of additional cropland. This is a lot given the scarcity of land in Japan.

A third case considered here is rice export from Thailand. Though Thailand looses water by exporting to Nigeria and Senegal by 1.7 Gm^3/yr and 1.8 Gm^3/yr respectively, it is saving water globally as the national water savings in Nigeria (3.2 Gm^3/yr) and Senegal (2.9 Gm^3/yr) are higher than the losses in Thailand (Figure 4.2). The main reason behind the global saving related to the trade between Thailand and Nigeria, is that rice yield in Thailand is 1.7 times higher than in Nigeria (Table 5.3). These two countries have crop water requirements of comparable magnitude (1000 mm/crop period). On the contrary, the main reason behind the global water saving by the trade between Thailand and Senegal, which both have a crop yield in the order of 2.5 ton/ha, is the difference in the crop water requirements in Thailand (945 mm/crop period) and Senegal (1523 mm/crop period). The export of rice from Thailand to five other trading partners (China, Indonesia, Iran, Malaysia and USA) is creating a global water loss of 5 Gm^3/yr. National water loss in Thailand is greater than the corresponding national water savings in these countries. This is due to the fact that rice yield in Thailand is low if compared to the countries where it exports to.

Table 5.3. Crop water requirements, crop yields and the virtual water content of rice in Thailand and its major trade partners. Period 1997-2001.

	Crop water requirement (mm/crop period)	Rice yield (ton/ha)	Virtual water content (m^3/ton)
China	830	6.3	1321
Indonesia	932	4.3	2150
Iran	1306	4.1	3227
Malaysia	890	3.0	2948
Nigeria	1047	1.5	7036
Senegal	1523	2.5	6021
Thailand	945	2.5	3780
USA	863	6.8	1275
Global average		3.9	2291

6. Global blue water savings at the cost of green water losses

The global water saving ΔS_g is made up of a *global blue water saving* ($\Delta S_{g,b}$) and a *global green water saving* ($\Delta S_{g,g}$) component:

$$\begin{aligned}\Delta S_g &= T \times (V_i - V_e) \\ &= T \times \left((V_{g,i} + V_{b,i}) - (V_{g,e} + V_{b,e}) \right) \\ &= T \times (V_{g,i} - V_{g,e}) + T \times (V_{b,i} - V_{b,e}) \\ &= \Delta S_{g,g} + \Delta S_{g,b}\end{aligned} \qquad (3)$$

Even if there is a net global water loss from a trade relation, there might be a saving of blue water at the cost of a greater loss of green water or vice versa. The case is elaborated with the example of Egypt's wheat trade. The virtual water content of wheat in Egypt is 930 m^3/ton. This is all blue water; the green component of the virtual water content of wheat is zero. Suppose that Egypt is importing *T* ton/yr of wheat from Australia. The virtual water content of wheat in Australia is 1588 m^3/ton. Wheat production in Australia is not 100% irrigated; it is assumed here that a fraction *f* of the virtual water content of wheat in Australia is green water. There is net global loss of *658T* m^3/yr in this trade.

$$\begin{aligned}\Delta S_g &= T \times (V_i - V_e) \\ &= T \times (930 - 1588) \\ &= -658T\end{aligned}$$

The global *green* water saving, $\Delta S_{g,g}$ (m^3/yr), in this case is always negative:

$$\begin{aligned}\Delta S_{g,g} &= T \times (V_{g,i} - V_{g,e}) \\ &= T \times (0 - f \times 1588) \\ &= -T \times 1588 f\end{aligned}$$

However, whether the global *blue* water saving $\Delta S_{g,b}$ (m^3/yr) is positive or negative depends upon the fraction *f* in the exporting country:

$$\begin{aligned}\Delta S_{g,b} &= T \times (V_{b,i} - V_{b,e}) \\ &= T \times (930 - (1 - f)1588) \\ &= T \times (-658 + 1588 f)\end{aligned}$$

There is net gain in global blue water resources as long as the blue water component of Australian wheat is smaller than in Egypt, i.e. if the fraction *f* in Australia is larger than 0.42. In a case of extreme drought, if the effective rainfall in Australia for wheat is zero (f=0) and all the evaporative demand is met by irrigation, all the losses are in blue water resources, which is 658T m^3/yr. In another extreme example, when the full evaporative demand of wheat in Australia is met by effective rainfall, so that no irrigation water is used (f=1), the global loss of green water will be 1588T, but we obtain a net global gain of blue water of 930T m^3/yr. Here, the gain in blue water is obtained at the cost of green water.

Since blue water resources are generally scarcer than green water resources, global water losses can be positively evaluated if still blue water resources are being saved. The classical example of trade that makes sense from both water resources and economic point of view is when predominantly rain-fed crop or livestock products from humid areas are imported into a country where effective rainfall is negligible. Also the import of products that originate from semi-arid countries that apply supplementary irrigation can be beneficial from a global point of view, because supplementary irrigation increases yields often more than double, a profitable situation that can never be achieved in arid countries where effective rainfall is too low to allow for supplementary irrigation, so that full irrigation is the only option.

7. Discussion

The volume of global water saving from the international trade of agricultural products is 352 Gm^3/yr (average over the period 1997-2001). The largest savings are from international trade of crop products, mainly cereals (222 Gm^3/yr) and oil crops (68 Gm^3/yr), owing to the large regional differences in virtual water content of these products and the fact that these products are generally traded from water efficient to less water efficient regions. Since there is smaller variation in the virtual water content of livestock products, the savings by trade of livestock products are less.

The export of a product from a water efficient region (relatively low virtual water content of the product) to a water inefficient region (relatively high virtual water content of the product) saves water globally. This is the physical point of view. Whether trade of products from water efficient to water inefficient countries is beneficial from an economic point of view, depends on a few additional factors, such as the character of the water saving (blue or green water saving), and the differences in productivity with respect to other relevant input factors such as land and labour. Besides, international trade theory tells that it is not the absolute advantage of a country that indicates what commodities to produce but the relative advantage (Wichelns, 2004). The decision to produce locally or to import from other sites should be made on the basis of the marginal value or the utility of the water being saved at the consumption site compared to the cost of import.

Saving domestic water resources in countries that have relative water scarcity by the mechanism of virtual water import (import of water-intensive products) looks very attractive. There are however a number of drawbacks that have to be taken into account as well. Saving domestic water through import should explicitly be seen in the context of:

- the need to generate sufficient foreign exchange to import food which otherwise would be produced domestically;
- the risk of moving away from food self sufficiency that associates with the fear of being held to political ransom;
- increased urbanization in importing countries as import reduces employment in the agricultural sector;
- reduced access of the poor to food; and
- increased risk of environmental impact in exporting countries, which is generally not accounted for in the price of the imported products.

Enhanced virtual water trade to optimise the use of global water resources can relieve the pressure on water scarce countries but may create additional pressure on the countries that produce the water-intensive commodities for export. The potential water saving from global trade is only sustainable if the prices of the export commodities truly reflect the opportunity costs and negative environmental externalities in the exporting countries. Otherwise the importing countries simply gain from the fact that they would have to bear the cost of water depletion if they would produce domestically whereas the costs remain external if they import the water-intensive commodities instead.

Since an estimated 16% of the global water use is not for domestic consumption but for export, global water use efficiency becomes an important issue with increasing globalisation of trade. Though international trade is seldom done to enhance global water productivity, there is an urgent need to address the increasing global water scarcity problem.

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Appendix I. Gross national savings and losses related to the international trade of agricultural products ($10^6 m^3/yr$). Period: 1997-2001.

	Gross national saving (Gm^3/yr)			Gross national loss (Gm^3/yr)		
	Related to import of crop products	Related to import of livestock products	Total saving	Related to export of crop products	Related to export of livestock products	Total loss
Afghanistan	770	7	777	191	1	191
Albania	1393	284	1677	35	49	83
Algeria	42460	3453	45913	441	43	484
Angola	3034	556	3590	800	0	800
Argentina	2732	463	3195	45952	4172	50124
Armenia	539	141	680	24	3	27
Australia	5242	949	6190	38214	25217	63431
Austria	5548	1864	7412	1996	2852	4848
Azerbaijan	1242	140	1382	1037	96	1132
Bahrain	298	102	399	32	10	41
Bangladesh	4172	118	4290	771	652	1424
Barbados	169	119	288	107	8	115
Belarus	2452	245	2698	125	119	245
Belgium-Luxembourg	37633	5678	43311	14688	9825	24513
Belize	29	31	60	456	5	461
Benin	664	51	715	1937	8	1944
Bhutan	144	8	152	6	0	6
Bolivia	2073	424	2496	1858	394	2253
Botswana	1467	239	1706	8	154	162
Brazil	27006	2573	29580	53713	11901	65614
Bulgaria	1677	1185	2861	1778	423	2202
Burkina Faso	431	31	462	1544	10	1554
Burundi	102	3	105	329	0	330
Cambodia	812	39	851	25	24	49
Cameroon	1781	54	1835	8300	4	8304
Canada	17967	5105	23072	48321	17424	65745
Cape Verde	153	9	161	2	0	2
Central African Rep.	132	2	134	650	0	650
Chad	155	5	160	1960	6	1966
Chile	3144	806	3949	1122	265	1386
China	45863	33654	79517	17736	6024	23761
Colombia	8938	364	9302	10783	444	11227
Congo, DR	814	134	947	796	0	797
Costa Rica	2307	111	2419	2979	365	3344
Côte d'Ivoire	2622	175	2797	35029	13	35041
Croatia	1902	785	2687	464	308	772
Cuba	3784	392	4176	8628	15	8643
Cyprus	1637	114	1751	245	66	311
Czech Republic	4602	577	5178	2039	856	2895

	Gross national saving (Gm^3/yr)			Gross national loss (Gm^3/yr)		
	Related to import of crop products	Related to import of livestock products	Total saving	Related to export of crop products	Related to export of livestock products	Total loss
Denmark	7537	1436	8972	2696	9451	12147
Dominican Republic	0	0	0	3309	67	3376
Ecuador	3863	98	3961	7385	67	7451
Egypt	13175	2046	15220	1755	221	1976
El Salvador	2184	393	2577	2718	72	2790
Eritrea	1234	17	1251	14	18	31
Estonia	2929	279	3207	399	162	561
Ethiopia	803	4	807	2143	90	2233
Fiji Islands	0	0	0	564	9	574
Finland	3338	399	3737	1015	569	1584
France	39080	9022	48103	43410	13206	56616
Gabon	431	134	565	70	0	70
Gambia	942	47	989	142	1	142
Georgia	265	106	371	347	217	563
Germany	64876	14091	78967	27630	17429	45058
Ghana	2265	97	2361	19501	2	19502
Greece	5303	5952	11255	4634	330	4964
Guatemala	2322	509	2831	5684	166	5850
Guyana	154	42	196	1033	1	1034
Haiti	0	0	0	253	5	257
Honduras	1809	202	2011	3043	77	3120
Hungary	3397	3544	6941	3495	8586	12081
Iceland	210	2	213	9	62	71
India	22582	362	22944	32411	3406	35817
Indonesia	26425	1763	28188	24749	369	25118
Iran	40078	769	40846	3587	314	3901
Iraq	15011	961	15972	703	5	707
Israel	8176	2307	10482	575	139	714
Italy	49095	38068	87163	12920	14899	27819
Jamaica	1361	258	1619	489	11	501
Japan	78930	17036	95966	951	955	1905
Jordan	7666	710	8375	97	163	261
Kazakhstan	562	72	633	7363	648	8011
Kenya	3473	15	3488	4638	161	4799
Korea, DPR	2809	100	2909	31	19	50
Korea, Republic of	32321	6198	38519	997	3930	4927
Kuwait	1614	579	2193	30	23	53
Kyrgyzstan	0	0	0	296	128	423
Laos	176	11	187	246	22	268
Latvia	1042	243	1284	387	192	579
Lebanon	3569	1924	5492	212	75	287

	Gross national saving (Gm^3/yr)			Gross national loss (Gm^3/yr)		
	Related to import of crop products	Related to import of livestock products	Total saving	Related to export of crop products	Related to export of livestock products	Total loss
Liberia	458	40	497	195	0	195
Libya	16869	1083	17952	102	51	153
Lithuania	1061	277	1338	339	591	930
Madagascar	435	8	443	3249	28	3277
Malawi	280	13	294	778	2	780
Malaysia	17209	2681	19890	23878	1012	24891
Mali	242	14	256	3368	9	3378
Malta	339	193	532	22	2	25
Mauritania	3175	78	3253	2	2	4
Mauritius	837	260	1096	647	33	680
Mexico	46275	36777	83052	11784	5747	17531
Moldova	190	33	223	1390	304	1695
Morocco	27920	630	28550	1327	225	1552
Mozambique	0	0	0	1112	6	1118
Myanmar	1450	134	1583	1447	100	1547
Namibia	50	3	53	3	99	102
Nepal	701	23	724	140	51	192
Netherlands	51302	6376	57678	34529	15028	49557
New Zealand	1573	186	1760	327	8984	9311
Nicaragua	964	116	1080	1721	535	2256
Nigeria	13605	466	14070	8673	64	8737
Nigeria	1254	35	1290	120	7	126
Norway	3135	147	3282	257	276	534
Oman	1695	559	2254	200	53	252
Pakistan	18467	181	18647	7381	612	7993
Panama	1322	138	1460	658	207	864
Papua New Guinea	0	149	149	6392	6	6398
Paraguay	443	87	530	5311	911	6222
Peru	7045	596	7641	2403	24	2427
Philippines	13527	2776	16304	8454	54	8507
Poland	10134	1034	11168	1927	2165	4092
Portugal	11027	3169	14196	2633	779	3412
Qatar	181	54	236	14	9	22
Romania	3443	1033	4475	2187	668	2855
Russian Federation	34011	17678	51689	8297	2500	10797
Rwanda	530	13	544	219	4	223
Saudi Arabia	18927	2611	21538	362	303	666
Senegal	6272	141	6413	3201	22	3223
Sierra Leone	252	19	271	95	0	95
Singapore	8207	1895	10102	4845	364	5208
Somalia	2815	7	2821	43	129	172

	Gross national saving (Gm^3/yr)			Gross national loss (Gm^3/yr)		
	Related to import of crop products	Related to import of livestock products	Total saving	Related to export of crop products	Related to export of livestock products	Total loss
South Africa	10566	1147	11713	6326	1312	7638
Spain	38530	11453	49983	18252	8540	26791
Sri Lanka	1643	157	1800	2381	46	2427
Sudan	1085	26	1110	7251	273	7524
Suriname	38	7	45	178	1	179
Swaziland	0	0	0	0	0	0
Sweden	5289	1215	6504	2034	808	2842
Switzerland	5773	571	6344	1163	401	1564
Syria	15448	608	16056	4025	512	4537
Taiwan	13360	4000	17360	329	3559	3888
Tanzania	1695	17	1712	3173	52	3225
Thailand	13611	2022	15633	38307	2856	41163
Togo	570	13	583	1920	2	1922
Trinidad and Tobago	811	210	1021	350	15	365
Tunisia	6216	955	7171	11013	71	11084
Turkey	17078	1032	18110	11069	335	11404
Turkmenistan	221	98	318	1071	27	1098
Uganda	2569	5	2574	4432	77	4510
Ukraine	2247	407	2654	8154	2447	10602
United Arab Emirates	0	0	0	4603	475	5078
United Kingdom	36398	9017	45415	8773	3785	12559
Uruguay	675	161	836	2009	3348	5357
USA	50601	27488	78089	134611	35306	169917
Uzbekistan	1252	281	1533	6533	55	6588
Venezuela	15823	648	16472	1394	389	1783
Viet Nam	2516	379	2894	11124	165	11289
Yemen	8047	587	8634	243	37	280
Zambia	383	12	395	508	14	522
Zimbabwe	0	0	0	3032	319	3351
Others	16471	4685	21156	7227	9330	16557
Total	1285537	319723	1605260	978566	274551	1253117

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