In: Trimble, S.W. (ed.) Encyclopedia of Water Science, Taylor & Francis, New York, 2007.

Virtual Water: Measuring Flows around the World

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Abstract
It is becoming increasingly important to put freshwater issues in a global context. International trade of commodities implies flows of virtual water over large distances, where virtual water should be understood as the volume of water required to produce a commodity. Virtual water flows between nations can be estimated from statistics on international product trade and estimates of the virtual water content of products. The global volume of virtual water flows related to the international trade in commodities is 1625 Gm^3/yr. About 80% of these virtual water flows relate to the trade in agricultural products while the remainder is related to industrial product trade. An estimated 16% of the global water use is for producing products for export. With increasing globalization of trade, global water interdependencies and overseas externalities are likely to increase. At the same time, liberalization of trade creates opportunities to increase global water use efficiency and physical water savings.

INTRODUCTION

It is generally argued that the river basin is the appropriate unit for analyzing freshwater availability and use. However, it becomes increasingly important to put freshwater issues in a global context due to the increasing water demand and scarcity throughout the world and the inherently global effects of climate change.[1,2] Another reason for taking a global perspective is the effect of global trade on the distribution of water resources use in the world. International trade of commodities implies large-distance transfers of water in virtual form, where virtual water is understood as the volume of water that is required to produce a commodity and that is thus virtually embedded in it.[3,4] One obtains a more realistic picture of water demand and scarcity of a country if one does not only look at actual water use in the country, but also at the virtual water flows entering and leaving the country. Jordan imports about 5 billion cubic meter of virtual water per year,[5] which is in sheer contrast with the 1 billion cubic meters of annual water withdrawal from domestic water sources. Egypt, with a total water withdrawal inside the country of 65 billion cubic meters per year, has an estimated net virtual water import of 11 billion cubic meters per year. The aim of this entry is to show how water requirements of products and international virtual water flows can be estimated and to summarize current knowledge on the size, the relevance, and the consequences of global virtual water flows.

Keywords: Water demand; Virtual water transfer; Global change; Water use efficiency; Trade.

THE VIRTUAL WATER CONTENT OF PRODUCTS

The virtual water content of primary crops is a function of crop water requirements and yields. Crop water requirements can be estimated with the Penman–Monteith equation, as promoted by the Food and Agriculture Organisation.[6] The term ‘virtual water’ includes both blue water use (the use of abstracted surface or groundwater) and green water use (the use of soil water originating from infiltrated rainwater). The virtual water content of live animals can be estimated based on the virtual water content of their feed and the volumes of drinking and service water consumed during their lifetimes. The procedure for assessing the virtual water content of a processed product (e.g., flour, cotton clothes, milk, cheese, eggs, or meat) is first to obtain the virtual water content of the input product (e.g., the primary crop or the slaughtered animal) and the water necessary to process it. The sum of these two components is then distributed over the various output products based on their product fraction (ton of processed product obtained per ton of input product) and value fraction (the market value of one output product divided by the aggregated market value of all output products).[5]

Based on the above methodology, the total water requirements of all sorts of products can be calculated. One cup of coffee requires, for instance, 140 liters of water, while a cup of tea takes 34 liters. Producing one hamburger requires 2400 liters of water. Wearing a cotton pair of jeans requires more than 11,000 liters. These are global average estimates. There are large differences as a result of production circumstances such as climate and applied technology.

Encyclopedia of Water Science DOI:10.1081/E-EWS-120042189

INTERNATIONAL VIRTUAL WATER FLOWS

Virtual water flows between countries ($m^3 yr^{-1}$) can be calculated by multiplying commodity trade flows (ton yr^{-1}) by their associated virtual water content (m^3 ton^{-1}). The latter is taken as the volume of water required to produce the commodity in the exporting country.[7]

The sum of international virtual water flows during 1997–2001 was 1625 Gm^3/yr.[5] The major share (61%) was related to international trade of crops and crop products. Trade in livestock products contributed 17% and trade in industrial products contributed 22%. These estimates have been based on an analysis of trade between 243 countries for which international trade data are available through the International Trade Center. In total, 285 crop products (covering 164 primary crops) and 123 livestock products (covering 8 animal categories) were considered. Trade in industrial products was dealt with all-inclusively as well, but in a more crude way—the average virtual water content per dollar of traded industrial product was a key parameter.

The total volume of international virtual water flows includes virtual water flows that are related to re-export of imported products. The global volume of virtual water flows related to export of domestically produced products is 1197 Gm^3/yr (Table 1). With a total global water use of 7451 Gm^3/yr, this means that 16% of the global water use is not meant for domestic consumption but for export. In the agricultural sector, 15% of the water use is for producing export products; in the industrial sector, this is 34%.

The major water exporters are the United States, Canada, France, Australia, China, Germany, Brazil, the Netherlands, and Argentina. The major water importers are the United States, Germany, Japan, Italy, France, the Netherlands, the United Kingdom, and China. Table 2 presents the virtual water flows for a number of selected countries. Import of water in virtual form can substantially contribute to the total water supply of a country. The Netherlands imports, for instance, a net amount of (virtual) water equivalent to the annual net precipitation in the country.

VIRTUAL WATER FLOWS BETWEEN WORLD REGIONS

The biggest net virtual water flows between thirteen world regions are shown in Fig. 1. The figure also shows the regional virtual water balances from 1997 to 2001. The green colored regions in the map have a net virtual water export and the red colored regions have a net virtual water import. The regions with the largest virtual water export are North and South America. The largest importers are Western Europe and Central and South Asia. The single most important intercontinental water dependency is Central and South Asia (including China and India), annually importing 80 Gm^3 of virtual water from North

Table 1 International virtual water flows and global water use per sector. Period 1997–2001

	Related to trade in agricultural products(Gm^3/yr)	Related to trade in industrial products(Gm^3/yr)	Related to trade in domestic water(Gm^3/yr)	Total(Gm^3/yr)
Gross virtual water flows				
Virtual water export related to export of domestically produced products	957	240	0	1197
Virtual water export related to re-export of imported products	306	122	0	428
Total virtual water export	1263	362	0	1625
	Agricultural sector	**Industrial sector**	**Domestic sector**	**Total**
Water use per sector				
Global water use (Gm^3/yr)	6391	716	344	7451
Water use in the world not used for domestic consumption but for export (%)	15	34	0	16

Table 2 Virtual water flows for a few selected countries. Period: 1997–2001

	Gross virtual water flows (10^6 m^3/yr)								Net virtual water import (10^6 m^3/yr)			
	Related to the trade in crop products		Related to the trade in livestock products		Related to the trade in industrial products		Total		Related to trade in crop products	Related to trade in livestock products	Related to trade in industrial products	Total
	Export	Import	Export	Import	Export	Import	Export	Import				
Argentina	45,952	3,100	4,178	811	499	1,732	50,629	5,643	−42,853	−3,367	1,233	−44,987
Australia	46,120	3,864	26,377	745	501	4,399	72,998	9,007	−42,256	−25,633	3,898	−63,991
Bangladesh	771	3,670	652	86	162	415	1,585	4,171	2,899	−566	254	2,586
Brazil	53,713	17,467	11,911	1,907	2,211	3,694	67,835	23,068	−36,246	−10,003	1,483	−44,767
Canada	48,321	16,190	17,424	4,952	29,573	14,289	95,318	35,430	−32,132	−12,472	−15,284	−59,888
China	17,429	36,260	5,640	15,247	49,909	11,632	72,978	63,139	18,831	9,608	−38,277	−9,839
Egypt	1,755	11,445	221	1,466	729	711	2,705	13,622	9,690	1,245	−18	10,917
France	43,410	40,577	13,222	11,829	21,873	19,761	78,505	72,166	−2,833	−1,393	−2,112	−6,338
Germany	27,630	59,751	17,432	16,062	25,416	29,757	70,478	105,570	32,121	−1,370	4,341	35,092
India	32,411	13,941	3,406	343	6,748	2,945	42,565	17,228	−18,470	−3,063	−3,803	−25,337
Indonesia	24,750	26,917	371	1,666	310	1,822	25,430	30,405	2,167	1,296	1,512	4,975
Italy	12,920	47,164	14,912	28,295	10,402	13,498	38,234	88,957	34,244	13,383	3,096	50,723
Japan	954	59,015	955	20,328	4,605	18,883	6,513	98,227	58,061	19,374	14,279	91,714
Jordan	97	4,103	165	462	25	228	287	4,794	4,006	297	203	4,506
Korea Rep.	997	24,801	3,930	6,097	2,219	8,344	7,146	39,242	23,804	2,166	6,126	32,096
Mexico	11,784	26,956	5,757	13,418	3,790	9,710	21,331	50,084	15,173	7,661	5,920	28,754
Netherlands	34,529	48,607	15,146	7,852	7,885	12,293	57,561	68,753	14,078	−7,294	4,408	11,192
Pakistan	7,381	8,879	612	98	1,526	579	9,518	9,555	1,498	−514	−947	37
Russia	8,297	30,925	2,503	12,243	36,932	2,899	47,732	46,067	22,627	9,740	−34,032	−1,665
South Africa	6,326	7,752	1,312	1,019	912	1,924	8,550	10,695	1,426	−293	1,011	2,145
Spain	18,252	30,483	8,541	5,972	3,753	8,520	30,545	44,975	12,231	−2,569	4,767	14,430
Thailand	38,429	9,761	2,856	1,761	1,655	3,596	42,940	15,117	−28,668	−1,096	1,941	−27,823
United Kingdom	8,773	33,742	3,786	10,163	5,113	20,321	17,672	64,226	24,968	6,378	15,208	46,554
USA	134,623	73,129	35,484	32,919	59,195	69,763	229,303	175,811	−61,495	−2,564	10,568	−53,491

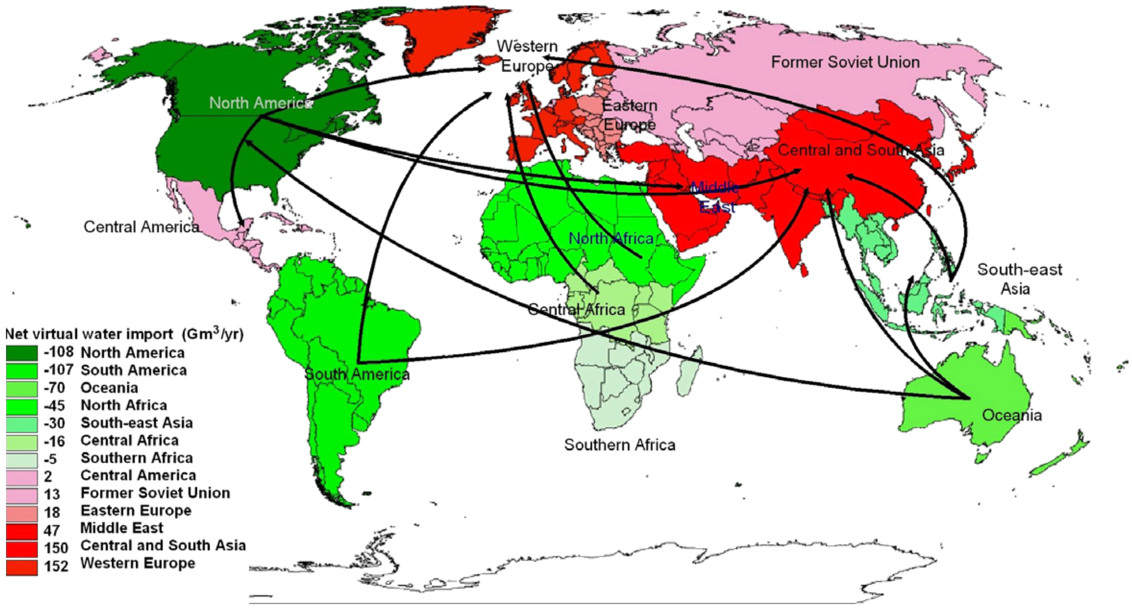

Fig. 1 Regional virtual water balances and net interregional virtual water flows (>10 Gm^3/yr) related to the trade in agricultural products. Period: 1997–2001.

America. This is equivalent to one-seventh of the annual runoff of the Mississippi. Ironically, the African continent, not known for its water abundance, is a net exporter of water to the other continents, particularly to Europe.

DISCUSSION

Globalization of freshwater brings both risks and opportunities. The largest risk is that the indirect effects of consumption are externalized to other countries. Because about 16% of global water use is for making export products, a substantial part of the water problems in the world can be traced back to production for export. Water in agriculture is still priced far below its real cost in most countries so that costs associated with water use in the exporting countries are not included in the prices of the products consumed in the importing countries. Efficient and fair trade would require restoring the link between consumers on the one hand and production costs and impacts on the other hand.

Another risk is that the national water security of many countries increasingly depends on the import of water-intensive commodities from other countries. Already today, Jordan annually imports a virtual water volume that is five times its own annually renewable water resource. Although saving their own domestic water resources, it increases Jordan's dependency on other nations. Other countries in the same region, such as Kuwait, Qatar, Bahrain, Oman, and Israel, but also European countries such as the United Kingdom, Belgium, the Netherlands, Germany, Switzerland, Denmark, Italy, and Malta, have a similar high water-import dependency.

An opportunity provided by reduced trade barriers is that virtual water can be regarded as an alternative source of water. Virtual water import can be used by national governments as a tool to release the pressure on their domestic water resources. In an open world economy, according to international trade theory, the people of a nation will seek profit by trading products produced with resources that are abundantly available within the country for products needing resources that are scarcely available. People in countries where water is a comparatively scarce resource could 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).

Finally, global virtual water trade can physically save water if products are traded from countries with high water productivity to countries with low water productivity. For example, Mexico imports wheat, maize, and sorghum from the United States, which require 7.1 Gm^3 of water per year in the United States. If Mexico would produce the imported crops domestically, they would require 15.6 Gm^3/yr. Thus, from a global perspective, the trade of cereals from the United States to Mexico saves 8.5 Gm^3/yr. Although there are examples where water-intensive commodities flow in the other direction—from countries with low water productivity to countries with high water productivity—the resultant of all international trade flows works into the positive direction. Global water saving as a result of international trade of agricultural products has been estimated at about 350 Gm^3/yr. This volume is equivalent to 6% of the global volume of water used for agricultural production.[8]

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