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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

$$UW_r = \frac{W_d \times N_d}{Y} \tag{1}$$

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,

$$UW_e = \frac{W_d \times N_d}{Y \times r_e} \quad (2)$$

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.

$$UW_t = \frac{W_d \times N_d}{Y \times r_t} \quad (3)$$

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.

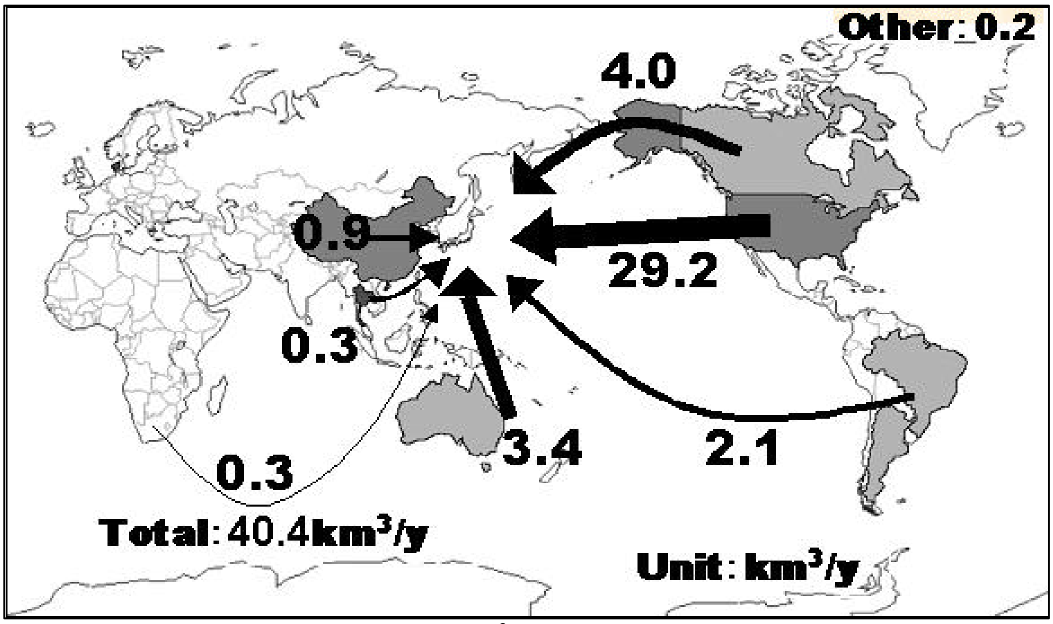

Figure 2.1. Annual virtual water import to Japan (m^3/y) embodied in grains. Based on crop yields in Japan for 1996-2000 and trade statistics for 2000.

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

$$E_c = \sum_i e_{ci} N_i \tag{11}$$

$$E_g = \sum_i e_{gi} N_i \quad (12)$$

and, of coarse, the total growing duration N_d satisfies

$$N_d = \sum_i N_i \quad (13)$$

DW was estimated by

$$DW = W_d \times N_d \quad (14)$$

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.

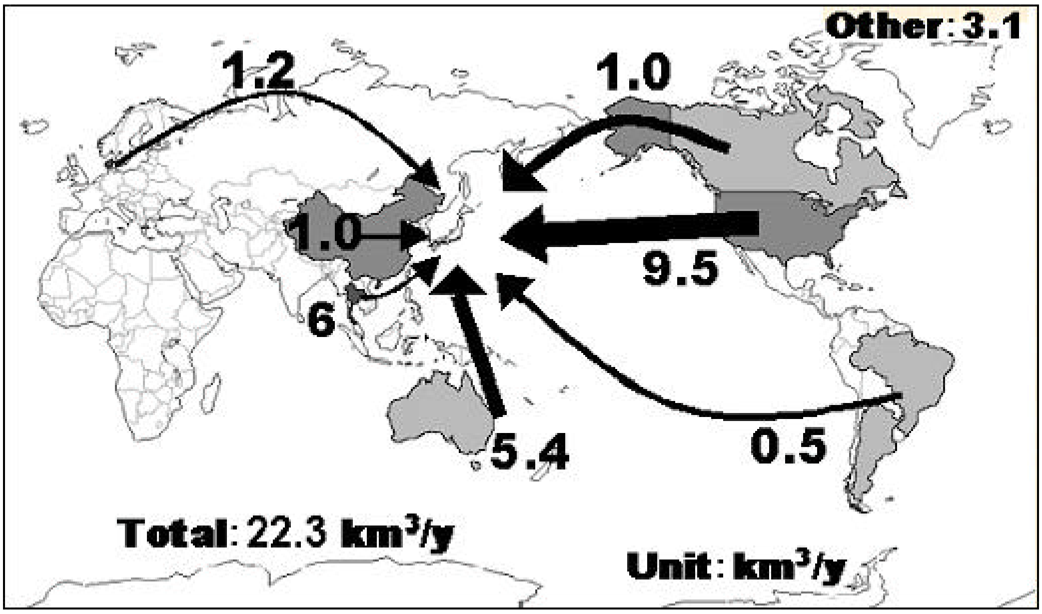

Figure 3.1.Annual virtual water import to Japan (m^3/y) embodied in meat. Based on crop yields in Japan for 1996-2000 and trade statistics for 2000.

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.

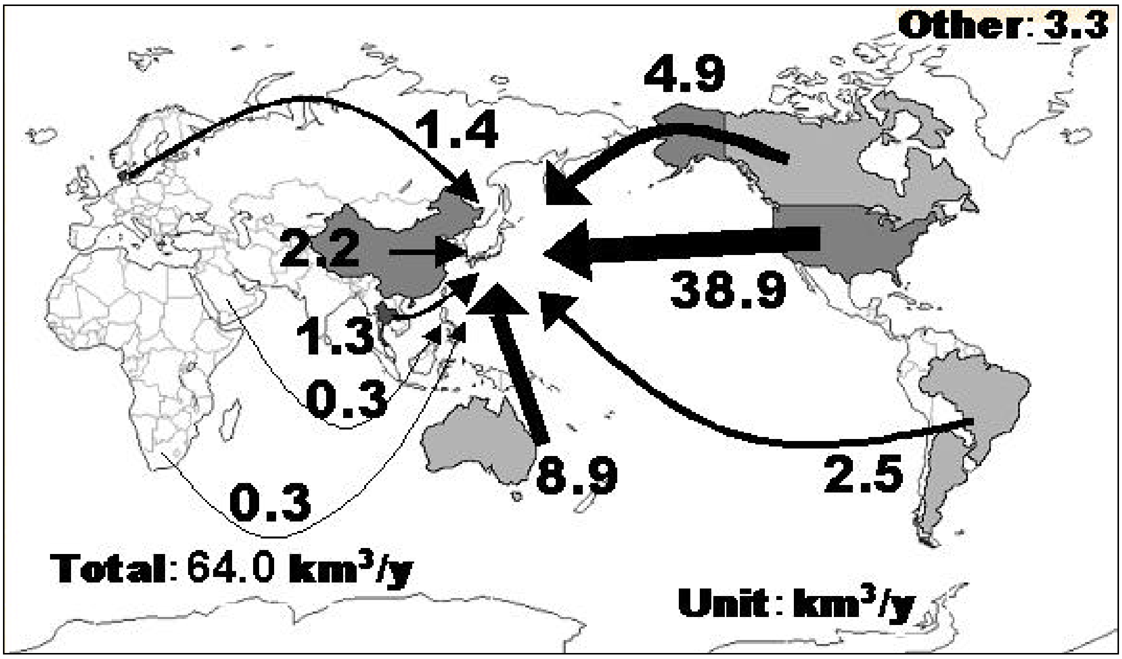

Figure 3.2. Annual virtual water import to Japan (m^3/y) in 2002 embodied in grain, meat, and industrial products.

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.

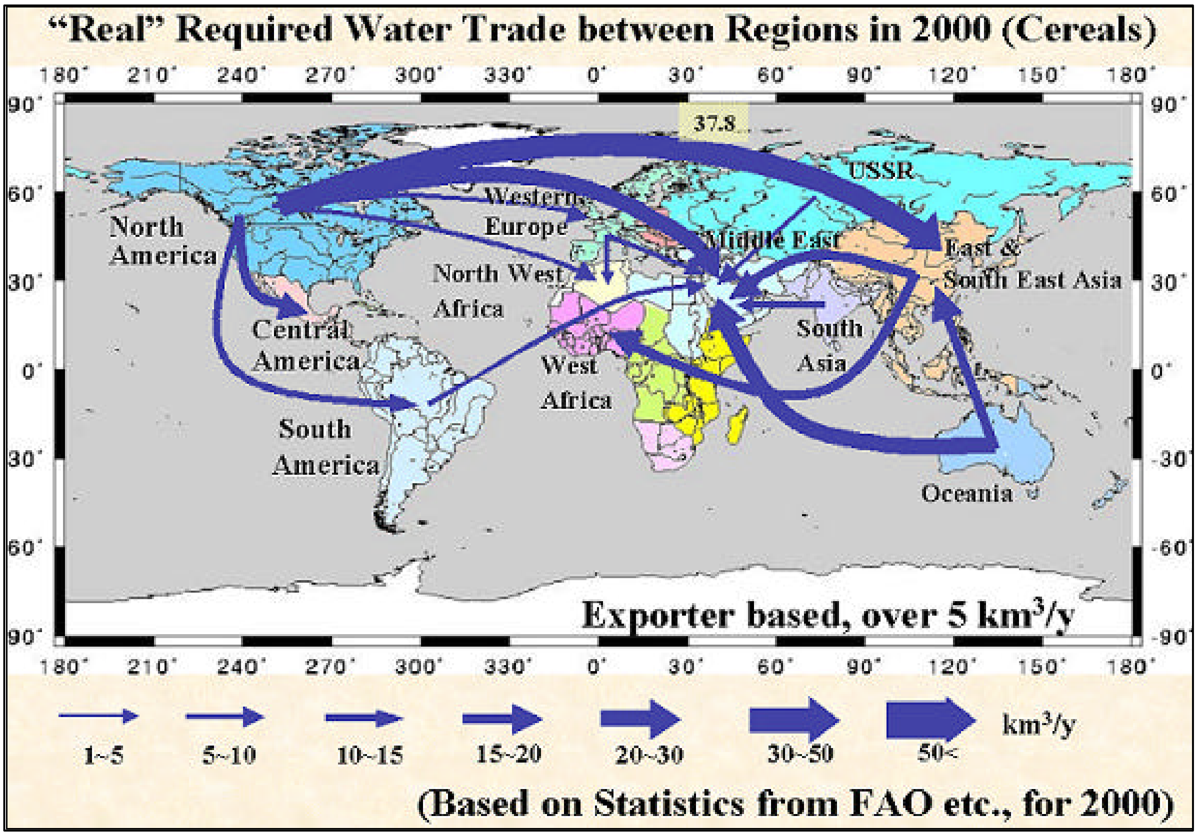

Figure 4.1. Annual really required water (real water) trade (km^3/y) for 2000.

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.

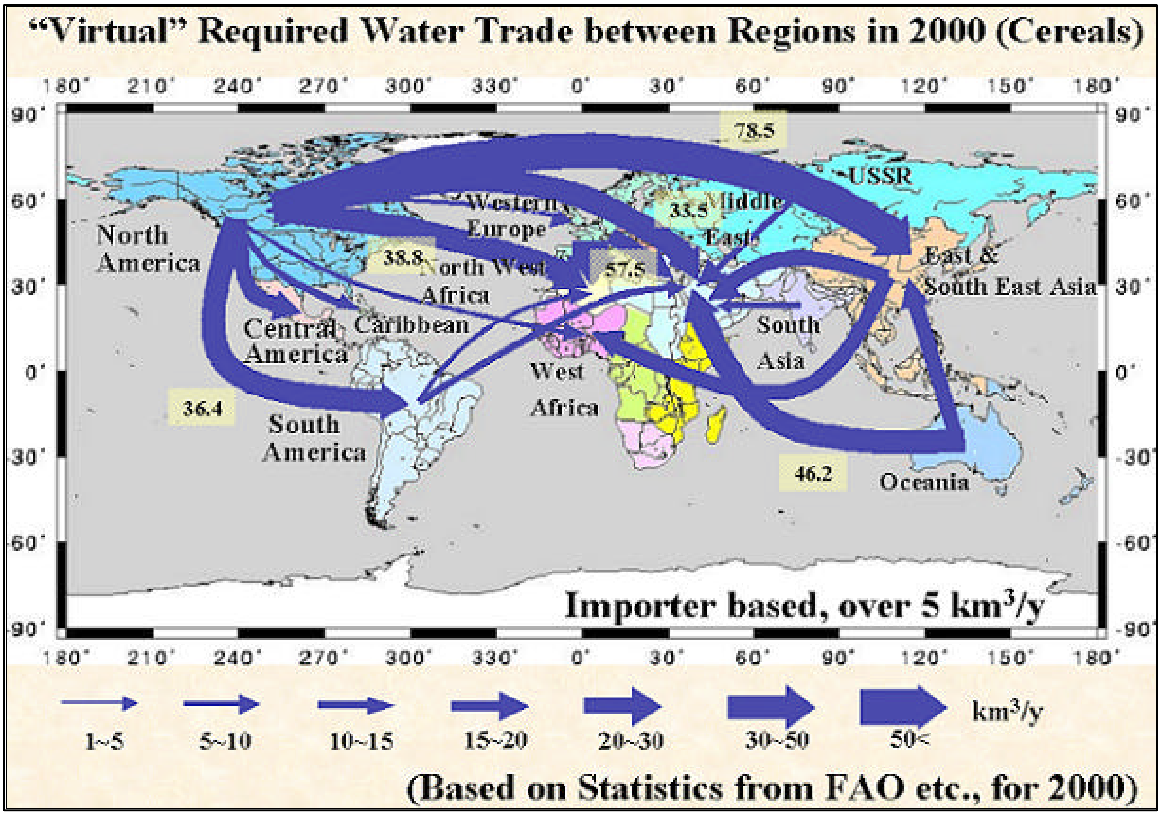

Figure 5.1. Annual virtually required water (virtual water) trade (km^3/y) for 2000.

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	Real	Volume	ratio to VW	IHE*
	(km^3/y)	(km^3/y)	(km^3/y)	(%)	(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.

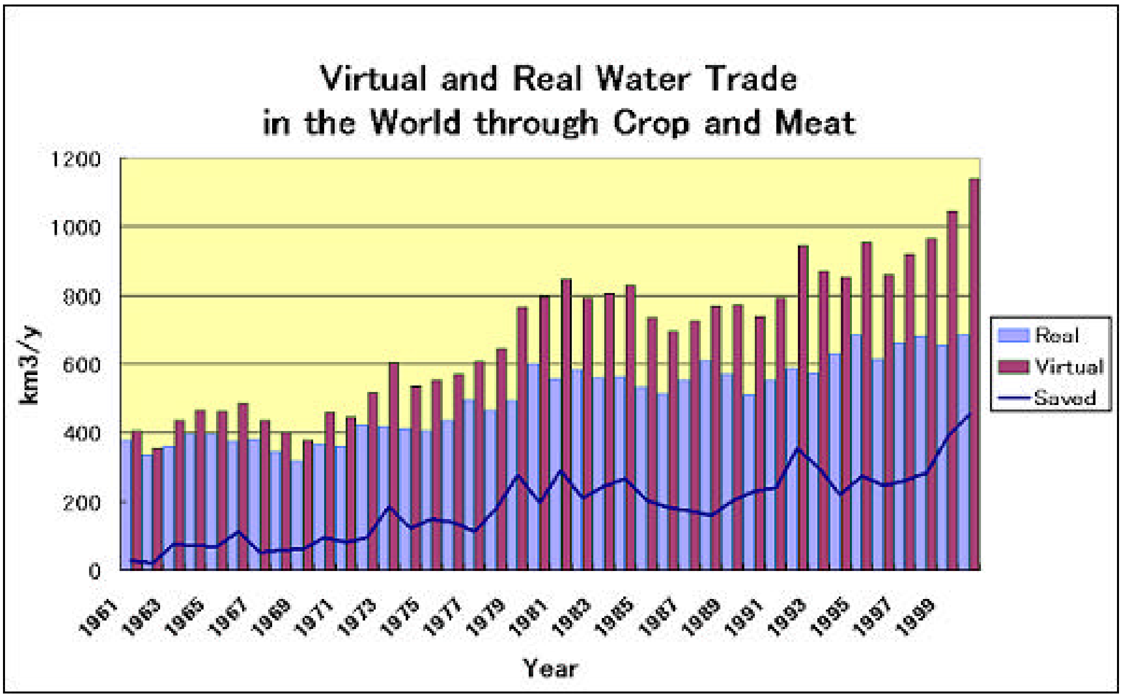

Figure 5.2. Temporal evolution of annual virtual and real water trade in the world from 1961 through 2000. Trade statistics between countries and crop yield are changing year by year.

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.

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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
	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	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
	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
Europe	**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