COMPREHENSIVE
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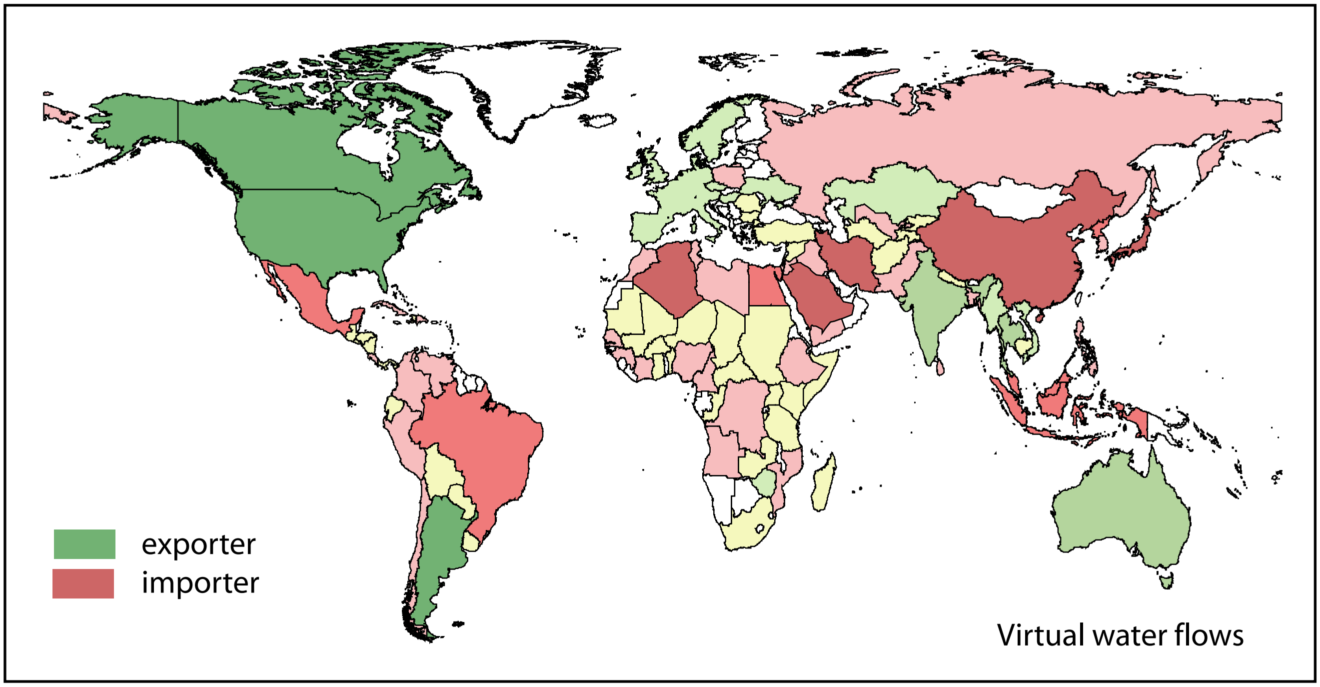
Research Report 4



Does International Cereal Trade Save Water? The Impact of Virtual Water Trade on Global Water Use

Charlotte de Fraiture, Ximing Cai, Upali Amarasinghe, Mark Rosegrant and David Molden

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Comprehensive Assessment of Water Management in Agriculture

The Comprehensive Assessment is organized through the CGIAR's System-Wide Initiative on Water Management (SWIM), which is convened by the International Water Management Institute. The Assessment is carried out with inputs from over 90 national and international development and research organizations—including CGIAR Centers and FAO. Financial support for the Assessment comes from a range of donors, including the Governments of the Netherlands, Switzerland, Japan, Taiwan and Austria; the OPEC Fund; FAO; and the Rockefeller Foundation.

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Summary

Virtual water refers to the volume of water used to produce agricultural commodities. When these commodities enter the world market, trade in virtual water takes place. Countries importing agricultural commodities essentially purchase water resources from exporting countries, thereby saving water they would otherwise have required.

Virtual water trade potentially reduces water use at two levels: national and global. Because it takes between 500 and 4,000 liters of crop water to produce one kilo of cereal, a nation reduces water use substantially by importing food instead of producing it on their own soil. At the global level, water savings through trade occur if production by the exporter is more water efficient than by the importer. Trade saves irrigation water when the exporting country cultivates under rain-fed conditions, while the importing country would have relied on irrigated agriculture.

A growing number of researchers propose international food trade as an active policy instrument to mitigate local and regional water scarcity. In their view, water short countries should import food from water abundant countries to save scarce water resources for "higher" uses, such as domestic purposes, industry and environment.

This report, analyzing the impact of international cereal trade on the global water use, argues that the role of virtual water trade in global water use is modest. In 1995, all importers combined, imported 215 million tons of grain for which they would have otherwise depleted 433 km^3 of crop water and 178 km^3 of irrigation water. Because of crop productivity differences between importers and exporters, cereal trade reduces global water use by 164 km^3 of crop water (effective rainfall or rainfall plus irrigation) and 112 km^3 of irrigation water depletion. This implies that without trade, global crop water use in cereal production would have been higher by 6 percent and irrigation depletion by 11 percent. Trade and associated savings will most likely increase in the coming decades.

Although the potential of trade to reduce water use may seem large—on paper—one should be careful when concluding that trade plays—or will play—an important role in global water scarcity mitigation. Occurring because of reasons unrelated to water, most trade takes place—and will continue to take place—between water abundant countries. Further, not all water "savings" can be reallocated to other beneficial uses. Furthermore, reductions in global water use relate to productivity differences between importers and exporters rather than water scarcity. Finally, political and economic considerations—often outweighing water scarcity concerns—limit the potential of trade as a policy tool to mitigate water scarcity.

Does International Cereal Trade Save Water?
The Impact of Virtual Water Trade on Global Water Use

Charlotte de Fraiture, Ximing Cai, Upali Amarasinghe, Mark Rosegrant and David Molden

Introduction

First introduced by Allan (1998 and 2001), the concept "virtual water" has since steadily gained in popularity.[1] Virtual water refers to the volume of water used in producing agricultural commodities. When these commodities enter the world market, importing countries essentially purchase water resources from exporting countries, thereby saving water they would otherwise have required. Thus, through the trade of agricultural commodities, a transfer in embedded water takes place, commonly referred to as virtual water trade (Allan 1998; Hoekstra and Hung 2003).

Virtual water trade potentially reduces water use at two levels: national and international. Because it takes between 500 and 4,000 liters of crop water to produce one kilo of cereal, a nation reduces water use substantially by importing food instead of producing it on their own soil. At the global level, water savings through trade occur if production by the exporter is more water efficient than by the importer. Trade saves irrigation water when the exporting country cultivates under rain-fed conditions, while the importing country would have relied on irrigated agriculture.

A growing number of researchers propose international food trade as an active policy instrument to mitigate local and regional water scarcity.[2] In their view, water-short countries should import food from water-abundant countries to save scarce water resources for "higher" uses, such as domestic purposes, industry and environment (Lant 2003). Others, however, point to political barriers and the possible adverse effects of imports on national rural economies and food security, especially in poor countries vulnerable to fluctuations in world market prices (Biswas 1999; Seckler et al. 2000; Wichelns 2001; Merret 2003).

Several studies quantify virtual water flows to underline the importance of water in international trade. Estimates vary between 10 and 15 percent of the global crop water depletion (Zimmer and Renault 2003; Hoekstra and Hung 2003; Oki et al. 2003). The analysis in this paper differs from previous studies in three aspects. First, the

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[1] Recent years saw several international workshops devoted to this topic: IHE-Delft, the Netherlands December 2002; a special session at World Water Forum in Kyoto, March 2003; and a special session at Stockholm Water Symposium, August 2003.

[2] Allan (2001) gives examples for the Middle East. Earle and Hurton (2003) explore trade as water management option for Southern Africa. Nakayama (2003) suggests a key role for virtual water in the Aral Sea and Mekong Basin. The World Summit on Sustainable Development (paragraph 92) implies that trade agreements under WTO should be evaluated on social and environmental impacts. Water use reduction through trade fits in this context.

impact of virtual water trade on global water use is measured by the difference in water use between importer and exporter.[3] Second, this analysis explicitly differentiates between rain-fed and irrigated agriculture and considers rainfall and irrigation water separately. Third, it distinguishes between food trade and water scarcity induced food trade.

Assessing past, present and future cereal trade, this report argues that the role of virtual water trade in global water use should not be overestimated. At present, 9 percent of total crop water depletion used for producing cereals is devoted to export. In the coming 25 years this may increase to 11 percent. Because major exporters are more efficient with water than importers, cereal trade reduces global crop water depletion by 6 percent. And, because main cereal exporters produce under rain-fed conditions and many importers would have relied on irrigation, trade reduces global irrigation water by 112 km^3, corresponding to 11 percent of the total irrigated depleted in cereal production.

Though trade has water-saving potential, its role in mitigating global water scarcity may not be as important as it seems at first sight. Occurring because of reasons unrelated to water, most trade takes place—and will continue to take place—between water abundant countries. Further, not all water “savings” can be reallocated to other beneficial uses. Moreover, political and economic considerations—often outweighing water scarcity concerns—limit the potential of trade as a policy tool to mitigate water scarcity.

The set-up of this report is as follows: section two gives definitions and describes the methodology. Data and data sources are listed in section three. Section four analyzes the present, past and future role of virtual water trade and associated water savings. Lastly, section five gives conclusions and discussion.

Definitions and Methods

Virtual water can be expressed as the volume of water used by the exporter to produce the traded amount of food or as the volume of water the importer would have used otherwise. The difference between the two is the net impact of trade on global water use. A further distinction is possible between crop and irrigation water depletion. Depletion is defined as a use or removal of water from a basin that renders it unavailable for further use (Molden et al. 2001). Crop water depletion includes crop evapotranspiration and losses because of reservoir evaporation, percolation to saline aquifers and pollution.

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[3] Most estimates are based on crop water requirements incurred by the exporter. Renault (2003) describes the concept of “savings because of trade” but does not apply it at a global level. Oki et al (2003) is the only study that provides an approximate estimate of water savings because of trade.

Crop Water Depletion

Virtual water flows can be expressed as the volume of water depletion incurred by the exporting country (equation 1) and as the amount that the importing country would have required otherwise (equation 2):

$$ETex_{i,j} = X_{i,j} \, .CW_i \qquad (1)$$

$$ETim_{i,j} = X_{i,j} \, .CW_j \qquad (2)$$

where

$ETex_{i,j}$ = crop water depletion used by the exporting country (m^3)

$ETim_{i,j}$ = crop water depletion the importer would have used (m^3)

$X_{i,j}$ = net cereal trade from exporter *i* to importer *j* (kg)

CW = crop water depletion per unit crop (m^3/kg)

i = exporting country

j = importing country

The volume of crop water depletion per unit crop is a function of climate (evapotranspiration) and crop yield (determined by, among others, farm inputs, soil characteristics and management, on-farm water). Expressed in cubic meter water per kilogram, it indicates how much water is needed to produce one unit of food. It is estimated from (equation 3):

$$CW = \frac{\text{amount of water}}{\text{amount of crop}} = \frac{10.DP_{\text{crop}}}{Y_{\text{crop}}} \qquad (3)$$

where

DP_{crop} = crop water depletion (mm)

Y_{crop} = crop yield (kg/ha)

The factor 10 is included to match units: 1 mm on one hectare corresponds with 10 m^3 of water. DP_{crop} includes crop evapotranspiration coming from precipitation and irrigation water.[4] It is computed from:

$$DP_{crop} = Peff + NET / EE \qquad (4)$$

where

$Peff$ = effective precipitation (mm)

NET = net irrigation requirements (mm)

EE = effective efficiency (%)

with:

$$NET = ET_{crop} - Peff \qquad (5)$$

$$ET_{crop} = k_c \; .ET_0 \qquad (6)$$

where

k_c = crop factor

ET_0 = reference evapotranspiration (mm)

Effective efficiency of irrigation water, defined as the depletion beneficially used by crops divided by total depletion (Keller and Keller 1995; Cai and Rosegrant 2002), shows how efficiently irrigation water is managed. The crop factor k_c and methods to estimate ET_0 can be found in FAO Irrigation and Drainage paper no.56.[5]

Equations (4) and (5) implicitly assume that, under irrigated conditions, all irrigation requirements are met. This assumption, needed because reliable estimates on deficit irrigation are lacking, may lead to an overestimation of irrigation water savings, especially in water scarce areas where deficit irrigation is common. In rain-fed areas, *NET* is zero and crop evapotranspiration is met exclusively by effective precipitation.

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[4] ET_{crop} originating from effective precipitation is also referred to as “green water” or “soil water.” The part of crop water requirements met by irrigation water is called “blue water.”

[5] http://www.fao.org/docrep/X0490E/x0490e00.htm

Irrigation Water Depletion

Analog to the crop water computations, irrigation water depletion can be expressed as the amount that the exporter used and the importer would have used:

$$IRex = X_{i,j} \,.\, IW_j \qquad (7)$$

$$IRim = X_{i,j} \,.\, IW_i \qquad (8)$$

where

$IRex$ = irrigation water depleted by the exporter (m^3)

$IRim$ = irrigation water the importer would have depleted (m^3)

IW = irrigation water depletion per unit crop (m^3/kg)

Irrigation water depletion is estimated from:

$$IW = \frac{10.NET / EE}{Y_{crop}} \qquad (9)$$

The factor 10 is needed to match units from mm per hectare to m^3.

Impact of Trade on Global Water Use

The impact of trade on the global crop water use is quantified as the difference of crop water depletion in the exporting country and the crop water “saved” in the importing country:

$$ETdif_{i,j} = ETim_{i,j} — ETex_{i,j} = X_{i,j}\,.(CW_j — CW_i) \qquad (10)$$

where

$ETdif_{i,j}$ = difference in crop water depletion between importer and exporter because of trade (m^3)

The impact of cereal imports on global water use into country j is given summing all bilateral flows:

$$TotIRdif_j = \sum_i IRdif_{i,j} \qquad (11)$$

At global level the impact is:

$$GlobETdif = \sum_i \sum_j ETdif_{i,j} \qquad (12)$$

A positive value of *ETdif* signifies that water “savings” because of trade occur as the exporter is more water efficient than the importing country. A negative value suggests that global crop water depletion increases because of trade since the exporter uses more water than the importer would have.

Similarly, the impact of international cereal imports on irrigation water depletion is quantified by:

$$IRdif_{i,j} = IRim_{i,j} — IRex_{i,j} = X_{i,j}.(IW_j — IW_i) \qquad (13)$$

at national level:

$$TotETdif_j = \sum_i ETdif_{i,j} \qquad (14)$$

and at global level:

$$GlobIRDIF = \sum_i \sum_j IRdif_{i,j} \qquad (15)$$

Estimation of Bilateral Trade Flows: Entropy

Data on bilateral cereal trade flows are available from databases such as FAOstat. But they are not always consistent. For example, the sum of bilateral flows reported in the FAOstat database “export of cereals by source and destinations” do not add up to the total import and export flows reported in the FAOstat database “agriculture and food trade.”[6] It is reasonable to assume that data on total imports and exports are more reliable than bilateral flows, because totals are easier to monitor than individual flows and reported bilateral flows may be incomplete. The question then is how to reconcile the inconsistencies between both data sources while optimally using the available information.

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[6] Available from website http://apps.fao.org.

Trade forecasts are provided by global water and food forecast models. But, the outputs from these models are usually given in an aggregated form, for example, the total export from or total import to a certain geographical unit. To be useful for this exercise, forecasted trade flows for the year 2025 need to be disaggregated into bilateral trade flows to compute the amount of water traded between countries. Because information is not enough for a unique solution, there are infinite ways to disaggregate the totals into bilateral flows.

To reconcile inconsistencies in data from different sources and disaggregate forecasted trade volumes into bilateral flows, this analysis uses the Bayesian statistical technique "Minimum Cross Entropy." It uses reported—but incomplete—bilateral flows and aggregated forecasted flows as prior information. Minimum Cross Entropy chooses a solution that is consistent with the totals and is "closest"in a statistical sense—to the bilateral flows known from data for the present or previous years. Technical details and mathematical formulations are given in the annex. The model equations are coded in GAMS and solved using the Conopt3 solver (Brooke et.al. 1988).

Cereals as an Indicator

Though they only constitute about half of all traded food stuffs (table 1), cereals are used as an indicator of the impact of trade on global water use for two reasons. First and most importantly, reliable data on actual and future bilateral trade flows only include cereal crops. Second, the bulk of the cereal trade occurs from the United States, Canada and the European Union, where grains are grown under highly productive rain-fed conditions, to countries that would have relied on irrigation—at least partly. So, the potential of cereal trade to save irrigation water is substantial.

TABLE 1.
Global trade in agricultural commodities in million tons.

	1995		2000	
Cereals	260.80	(13%)	287.69	(14%)
Fruit and vegetables	100.79	(24%)	116.56	(25%)
Feeding stuff (incl. cereals)	82.27	(10%)	89.37	(10%)
Meat and meat products	18.88	(9%)	20.00	(8%)
Dairy products	16.46	(50%)	24.44	(64%)

Source: FAO stat database (last accessed June 2003), includes Europe intra-trade.

Note: In brackets percentage of total production.

Data and Data Sources

The data for this analysis come from several sources. Bilateral trade flows and total imports/exports for different cereals for the years 1981 to 2000 are taken from the FAOstat database.[7] Information required for estimating crop and irrigation water productivity is taken from the IWMI "World Water and Climate Atlas"[8] and data used in the IMPACT-WATER model (Rosegrant et al. 2002). This model uses 0.5 by 0.5 degree GIS coverage of climate variables and irrigated areas developed by Kassel University. It provides estimates on effective efficiency, information on cropping patterns and crop productivity based on FAO data (Cai and Rosegrant 2002). Projected cereal trade for the year 2025 is taken from the IMPACT-WATER model projections, disaggregated into smaller geographical units using PODIUM.[9]

Water Productivity Estimates

Water productivity is a function of climate variables, water use efficiency and crop yields. Crop yields depend on agronomic factors such as agro-inputs, seed quality, soil characteristics and on-farm water management. Average cereal yields among major importers and exporters vary by a factor of 7, from 1.0 tons per hectare in sub-Saharan Africa to 6.9 tons per hectare in France. Crop water requirements vary from 350 to 800 mm per season. Net irrigation requirements range from close to zero (Canada) to 100 percent of total crop water (Egypt), while estimated effective efficiencies range from 85 percent (Israel) to 55 percent (India). Most major exporters (USA, Canada and France) combine high cereal yields with relatively low evapotranspiration, resulting in high crop water productivity. On the other hand, some importing countries (Saudi Arabia, sub-Saharan Africa) combine relatively low yields with high evapotranspiration and thus exhibit low "crop-per-drop." The wide ranges in yields, climate variables and efficiencies explain the large variation in estimated crop and irrigation water productivity. Tables 2 and 3 present water productivity values for major exporting and importing countries, as estimated by using equations (3), (4), (5) and (6).

The results and conclusions of the analysis presented in this report are sensitive to the values of crop water productivity. Yet, there is a lot of uncertainty in crop water productivity estimates. Though detailed GIS coverage of climate variables is available, several factors hamper the reliability of water productivity estimates. First, comprehensive and reliable information on cropping patterns—i.e., planting and harvesting dates— is hard to find at a global scale. A second problem occurs because of the difference between potential evapotranspiration estimates derived from climate variables and actual evapotranspiration. Information on actual values being scarce, most studies use potential values, thus overestimating water use. A third problem arises from the lack of production data disaggregated into irrigated and rain-fed agriculture. Lastly, reported data on irrigation water use are often inconsistent, incomplete and outdated. The analysis in this report uses estimates on yields and irrigation water use derived from the IMPACT-WATER model (Rosegrant et al. 2002).

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[7] Website: http://apps.fao.org/page/collections?subset=agriculture under headings "export of cereals by source and destinations" and "agriculture and food trade." Last accessed, July 2003.

[8] Website: http://www.iwmi.cgiar.org/WAtlas/atlas.htm

[9] IMPACT-WATER is a water-and-food forecast model developed by the International Food Policy Research Institute (Rosegrant et al. 2002). PODIUM is a global scenario tool developed by the International Water Management Institute (Seckler et al. 2000; Fraiture et al. 2001).

TABLE 2.
Water productivity of cereals in exporting countries, expressed in kg per m^3 of crop water depletion (1995).

Major cereal exporter	Rice	Wheat	Maize	All cereals	% of total crop ET originating from irrigation
USA	0.52	0.72	1.50	1.26	15%
EU 15	0.79	1.52	1.64	1.59	8%
Canada	0.53	0.80	0.79	0.78	4%
Argentina	0.45	0.37	0.63	0.49	5%
Australia	0.57	0.53	0.86	0.54	25%
Thailand	0.31		0.62	0.36	51%
India	0.27	0.39	0.23	0.31	42%
All exporters average	0.41	0.70	1.11	0.81	24%
World average	0.42	0.56	0.74	0.60	34%

Local studies, illustrating the wide variation of water productivity in irrigated agriculture, provide some kind of verification of the values used in this study. Though country averages are generally lower, case studies provide an idea of the order of magnitude. Comparing 40 irrigation schemes in 12 countries over the world, Sakthivadivel et al. (2001) find water productivities ranging from 0.5 to 1.6 kilogram per cubic meter crop water evapotranspiration for wheat and 0.4 to 1.1 kg/m^3 for rice. Tuong and Bouman (2003) obtain values ranging from 0.4 to 1.6 kg/m^3 for rice (India and Philippines), 0.6 to 1.5 kg/m^3 for wheat (India and China) and 1.7 to 2.8 kg/m^3 for maize (USA). Taking a case study from Pakistan, Bastiaanssen et al.

TABLE 3.
Water productivity of cereals in importing countries, expressed in kg per m^3 of crop water depletion (1995).

Selected cereal importer	Rice	Wheat	Maize	All cereals	% of total crop ET originating from irrigation
China	0.73	0.78	0.84	0.78	36%
Japan	0.74	0.74		0.74	65%
Korea, (Rep)	0.49	0.31	0.59	0.52	54%
Brazil	0.31	0.35	0.50	0.45	47%
Indonesia	0.51		0.48	0.51	22%
Egypt	0.62	0.75	0.93	0.79	97%
Saudi Arabia	0.31	0.23	0.37	0.24	88%
sub-Saharan Africa	0.15	0.22	0.23	0.22	4%
All importers average	0.53	0.48	0.51	0.50	39%
World average	0.42	0.56	0.74	0.60	34%

(2003) report a water productivity of 0.6 kg/m^3 for wheat and 0.4 kg/m^3 for rice. And, in their literature review of 82 case studies, Zwart and Bastiaanssen (forthcoming) find the wide range of 0.2 to 4.0 kg/m^3 for irrigated maize, 0.4 to 1.7 kg/m^3 for rice and 0.1 to 2.5 kg/m^3 for irrigated wheat.

In view of recent studies warning of increasing global water scarcity, the debate on water productivity will gain in importance. Because reliable estimates are essential, this topic deserves a separate study, beyond the scope of this report.

Results

The quantification of global virtual water flows is conducted at three time scales. First, a detailed analysis is presented for the year 1995 (the base year). Second, to avoid misleading conclusions based on one point in time, a time series analysis for the period 1981–2000 is presented. Because of data limitations, the level of detail in the time series analysis is less than for the base year. Third, to gauge possible changes in the coming decades, a projection is made for the year 2025, based on the trade forecasts resulting from the IMPACT-WATER model (Rosegrant et al. 2002).

Base Year 1995

Virtual water flows can be expressed in several ways. First, virtual water can be measured in crop water depletion or in irrigation water depletion. Crop water depletion comes from effective precipitation (i.e., soil water or “green” water) and irrigation (i.e., “blue” water). Irrigation water depletion consists the volume of “blue” water depleted in crop production and is, by definition, smaller or equal to crop water depletion. Second, a distinction can be made between the water used by the exporter and the volume saved by the importer. The difference between the two is the net impact of trade on global water use. If the exporter is more productive per unit crop water than the importer, trade reduces global water use (“savings through trade”). Conversely, if the amount used by the exporter is bigger than what the importer would have used, trade increases global water use (“losses through trade”).

This section first describes cereal trade patterns and related virtual water trade maps. It proceeds with quantifying the volume of water used by exporters, as compared to total global water use. It then analyzes the impact of trade in terms of reduction of water use at national and global level. It concludes with a discussion on the role of water scarcity in cereal trade.

Cereal Trade Patterns and Virtual Water Maps

Global cereal production in the year 1995 amounted to 1,724 million tons of which 12 percent was traded. Accounting for about half of the global cereal exports, the USA is by far the biggest exporter. Five regions—the USA, Canada, Argentina, Australia and the European Union—where cereals crops are mainly grown under rain-fed conditions, make up for 80 percent of all cereal exports. Importers are more diverse: around 25 countries in Asia, the Middle East and

Africa account for 80 percent of all imports. China, Japan, Korea, Indonesia, Egypt, Mexico and Iran figure among the top 10 importers. Bilateral cereal trade flows between major exporting and importing countries for 1995 are presented in table 4.

The global map in figure 1 shows net virtual water flows in 1995 expressed in crop water depletion. The quantity of virtual water leaving exporting countries, depicted in green, is measured as the amount depleted by the exporter. Virtual water coming into net importing countries, depicted in red, is expressed as the volume they would have used otherwise. For example, the USA, exporting some 104 million tons of grain for which 83 km^3 of crop water was depleted, is depicted in dark green. Japan, importing 27 million tons of grain in 1995, would have required 37 km^3 of crop water to grow the equivalent of cereal imports on its own soil and is thus shown in dark red.

Following the same convention, figure 2 shows the virtual flows expressed in irrigation water depletion. For example, in 1995 the European Union, depicted in light green, exported 22 million tons of grain, for which it used 1.2 km^3 of irrigation water (most crop water is met by precipitation). Egypt, depicted in red, imported some 8 million tons of grain for which it would have required 10 km^3 of irrigation water.[10]

The pattern emerging from the maps follows the cereal trade pattern observed in 1995, with the USA, the European Union, Australia and Argentina exporting large quantities of virtual water, and Japan, Brazil, Indonesia, Iran and Saudi Arabia importing large volumes of virtual water.

India and China deserve special attention. In 1995, India was one of the larger virtual water exporters, while China fell in the category of major importers. But expressed in percentage of domestic consumption, both countries were close to self-sufficiency in grains. In the years 2000 and 2002, China was a net exporter of grains. Over the last decade grain imports/exports in both countries fluctuated around zero percent of total consumption. Because of the size of grain consumption and production in India and China, imports or exports fall in the extreme categories. This illustrates the importance of Chinese and Indian food production and consumption in global water use estimates. Because the maps in figures 1 and 2 are based on one year (1995), they should be interpreted with care. Section 4.2 describes the results of a time series analysis.

Strikingly, sub-Saharan African countries do not feature in the maps as major importers, despite low agricultural production. There are two reasons: first, because diets in these countries are based on tuber crops, as staple food and cereals are not always adequate indicators of food imports. Second, calorie intakes of these countries feature among the lowest in the world according to data from the FAOstat database. Although crop production falls short compared to an adequate consumption level from a nutritional view, these countries do not have the resources to import. Imports averaged around 10 percent of the total food supplies in the late 1990s. The food aid share of imports peaked in the late1980s at approximately 40 percent. In more recent years, that share has averaged less than 20 percent of imports (USDA 2001).

Water Depleted by Exporters

In 1995, it took 2,875 km^3 of *crop water* depletion to produce 1,724 million tons of cereals—the world's total grain production. Exporters used 269 km^3 of crop water depletion to produce the 215 million tons that were traded.[11] In other words, cereal trade measured in tons amounted to 13 percent of the production. But, expressed in crop

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[10] This is measured in irrigation water depleted. Diversions will be higher, depending on basin efficiency.

[11] This is excluding 40 million tons of cereal trade within the European Union.

TABLE 4.
Bilateral cereal trade flows between major importers and exporters* in 1995, in million tons.

Import/ Export	China	Japan	Korea Rep	Brazil	Indonesia	Egypt	Mexico	Iran	Algeria	Saudi Arabia	SSA***	World total
USA	19.19	20.91	11.08	1.57	2.49	7.57	5.99	1.45	1.89	1.35	1.70	104.19
Canada	2.91	2.98	0.17	0.93	0.08		0.16	1.03	0.09	1.80	0.69	21.86
Argentina	0.26	0.64	0.38	5.19	0.87		0.19			0.10	0.12	13.88
Australia	0.78	2.45		0.14	0.10			0.19	0.11		0.96	10.69
EU(15)**	3.33	0.17	0.66	0.63		0.17		1.08	3.62	0.71	0.93	22.43
Thailand	1.54				1.20			1.08			0.42	6.35
Hungary								0.10			0.46	4.11
Vietnam	0.73				0.58					0.13		2.03
India					2.30			0.23		1.43	0.39	6.22
World total	28.80	27.24	12.40	8.59	7.73	7.92	6.41	5.22	5.88	5.53	5.89	215.00

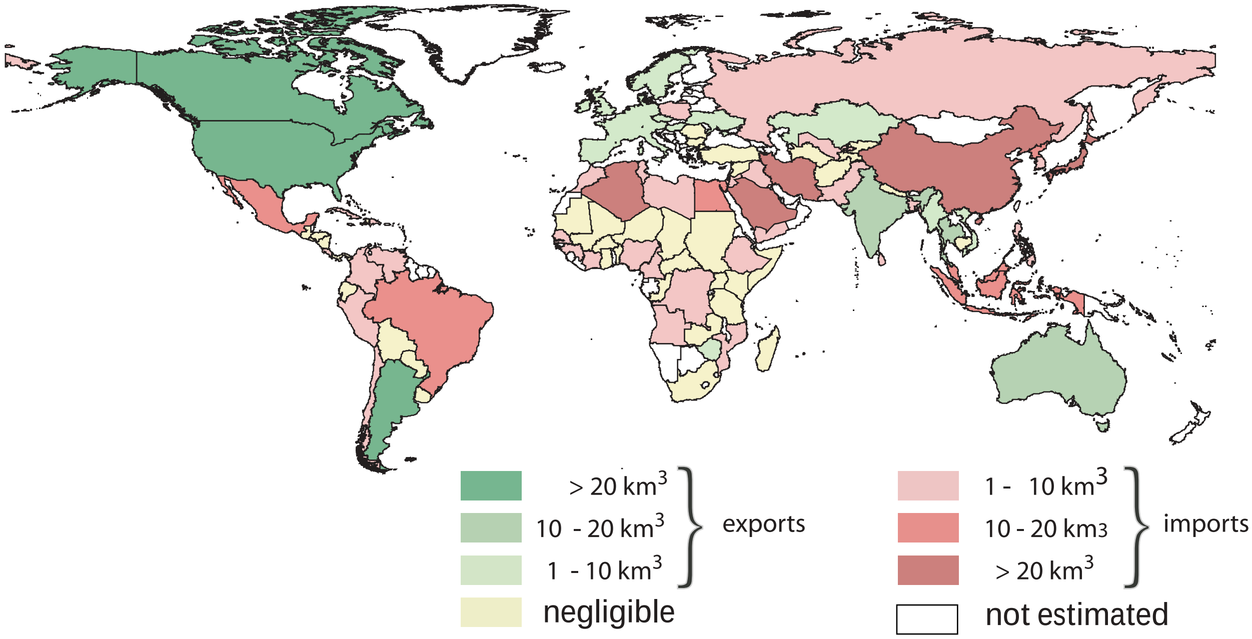
Source: Minimum cross entropy estimates based on FAOstat databases (last accessed July 2003).

Notes: * computed from the sum of rice, wheat and coarse grains.

** EU (15): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK; excludes intra-trade

*** sub-Saharan Africa: Burkina, Chad, Ethiopia, Mali, Mauretania, Niger, Nigeria, Somalia, Sudan, Benin, Cameroon, Centr. Afr. Rep, Congo, Zaire, Ivory Coast, Ghana, Guinea and Senegal.

FIGURE 1.
Virtual water flows due to cereal trade in 1995, expressed in crop water depletion.



water depletion, about 9 percent was traded. This difference is explained by the differences in crop water productivity between importers and exporters. On a global average, it takes 1.70 m^3 of crop water depletion to produce one kilogram of cereal, but as table 2 makes clear, most major exporters (USA, Canada and Europe) are more efficient with water. On average, the exporters used 1.23 m^3 of crop water depletion per kilogram of grain while importers used 2.05 m^3 per kilogram. The estimate presented here is lower than the previous estimates. Hoekstra and Hung (2003) estimate that 13 percent of total crop water is traded, while 412 km^3 is used to produce the traded cereals. Oki et al. (2003) estimate 472 km^3 used by cereal exporters. Differences are explained by the different assessments of water productivity.

For the global cereal production in 1995 roughly 979 km^3 of *irrigation* water was depleted, but only 67 km^3 (or 7%) was used for producing grains for export. Two interesting observations on irrigation water use can be made here:

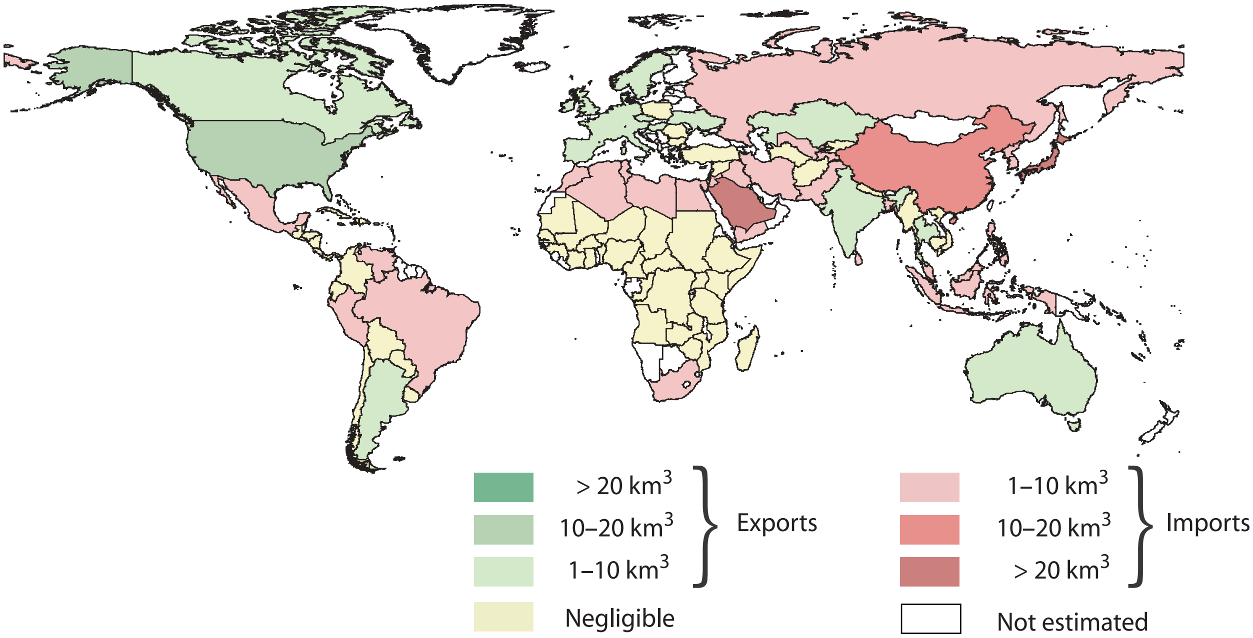
1) Effective precipitation—as opposed to irrigation—is the main source of crop water evapotranspiration in global cereal production. About 65 percent comes from effective precipitation. This estimate is almost equal to the estimate by Rockström et al. (1999) who put it at two thirds.

2) In producing cereals for export, less than a quarter of the required crop evapotranspiration comes from irrigation water because major exporters produce under rain-fed conditions and most requirements are met by precipitation.

Water "Saved" by Importers at the National Level

At the national level, an importer "saves" water it would have otherwise required. For example, in 1995, Egypt imported 7.9 million tons of grain, mainly from the USA and the European Union, thereby "saving" some 9.9 km^3 of irrigation water

FIGURE 2:
Virtual water flows due to cereal trade in 1995, expressed in irrigation water depletion.



it would have required to produce this domestically. Japan imported about 27 million tons of grain from the USA, Canada and Australia, for which it would have needed some 37 km^3 of water (rain plus irrigation) to produce on its own soil. All importers combined imported 214 million tons of grain for which they would otherwise have required 433 km^3 of crop water and 179 km^3 of irrigation water depletion.

Water "Saved" at the Global Level

At the global level, reductions in global water use occur if production by the exporter is more water efficient than by the importer. For example, the USA exported the equivalent of 16.6 km^3 of crop evaporation to Japan for which Japan would have needed 28.1 km^3. By importing from the USA, Japan reduces global water use by 28.1 – 16.6 = 11.5 km^3.

In case the importer is more water efficient than the exporter, trade increases water use. For example, Indonesia imported 2.3 million tons of grain from India, for which it would have required 16.7 km^3. To produce this cereal, India depleted 17.4 km^3, thus increasing global water use by 0.7 km^3. Another example, Sudan imported grain from South Africa, the Russian Federation and others, thereby reducing global crop water depletion by 1.1 km^3. But the globe "loses" 0.2 km^3 of irrigation water depletion because Sudan would have produced under rain-fed condition, while exporters partly relied on irrigation. Tables 5 and 6 compare the amount of water "saved" by importers and depleted by exporters. The columns list the main importers and the rows correspond to the major exporters. The top number in each cell represents the amount of water that the importer would have needed to produce the cereals domestically, as computed by equation (2) and (8). The numbers in brackets reflect the amount that the exporter used for its production, computed by equation (1) and (7). The difference is the impact of trade on global water use (equation 10 and 13). Table 5 shows the bilateral virtual water flows measured in crop water depletion; table 6 shows the same, measured in irrigation water depletion.

Overall, exporters are more water efficient than importers and cereal trade "saves" water. Without trade, crop water depletion would have been higher by 163 km^3—corresponding with 6 percent of the total cereal crop water depletion. The impact of cereal trade on global irrigation water depletion is more pronounced. In 1995, cereal trade reduced global irrigation water depletion used in cereal production by 11 percent (112 km^3).

Water Scarcity and Trade

The role of water scarcity in shaping virtual water trade flows is limited. Occurring for reasons unrelated to water, most trade takes place between water abundant countries. Yang and Zehnder (2002) assess that 20 percent of the cereal trade is water scarcity induced. Japan, the largest importer, requires the "virtual land" embedded in the cereals, as opposed to the "virtual water" content (Oki et al 2003). Other countries may import because of the comparative advantage in other sectors, labor constraints or political reasons. To assess the role of water scarcity in trade, this analysis relates observed trade flows to the water scarcity indicator used by Seckler et al. (2000). It is assumed that all importing countries considered water scarce import because of water scarcity related reasons. According to this guideline, 23 percent of all cereal trade in 1995 occurs from water abundant to water scarce areas. Hence, only 2 percent of cereal crop water depletion is devoted to produce cereals for water scarcity induced trade (figures 3 and 4).

Looking at these numbers, it is clear that at present water scarcity plays a minor role in shaping global cereal trade flows. For individual countries this may be different.

FIGURE 3.
Water depletion used in global cereal production (km^3) 1995.

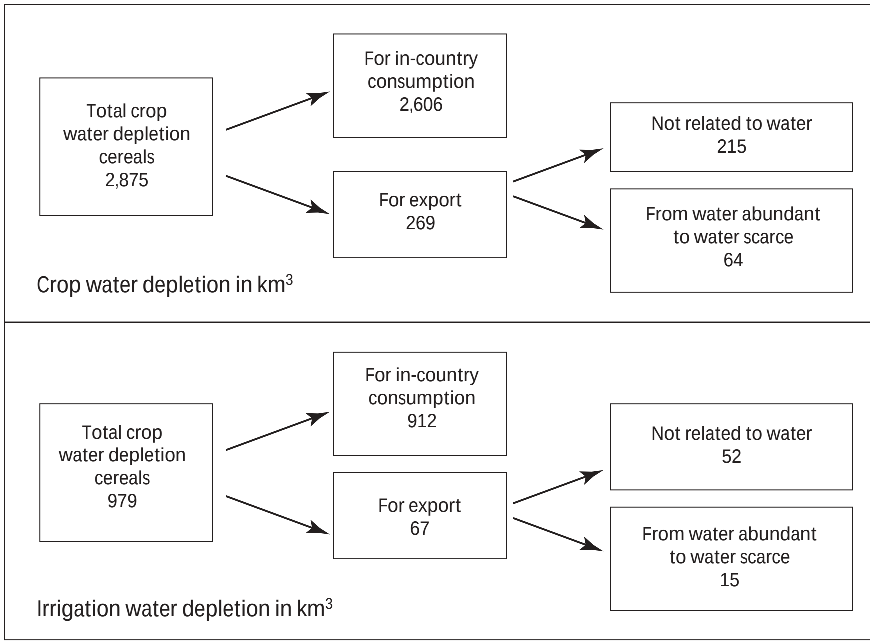


TABLE 5.
Virtual water flows between major cereal importers and exporters in 1995, measured in cereal crop water depletion (km^3).

Import/ Export	China	Japan	Korea Rep	Brazil	Indonesia	Egypt	Mexico	Iran	Algeria	Saudi Arabia	World total
USA	24.59	28.11	12.91	3.51	4.94	9.64	13.09	6.00	7.83	5.59	197.04
	(15.20)	(16.56)	(8.77)	(1.25)	(1.98)	(6.00)	(4.74)	(1.15)	(1.50)	(1.07)	(82.52)
Canada	3.73	4.00		2.07	0.15		0.35	4.25	0.36	7.44	43.77
	(3.74)	(3.82)		(1.19)	(0.10)		(0.20)	(1.32)	(0.11)	(2.31)	(28.07)
Argentina	0.33	0.86	0.45	11.58	1.71		0.42	0.18		0.43	31.56
	(0.53)	(1.31)	(0.78)	(10.60)	(1.69)		(0.38)	(0.09)		(0.21)	(28.34)
Australia	1.00	3.30	0.08		0.20	0.08		0.80	0.46	0.26	24.26
	(1.45)	(4.56)	(0.12)		(0.19)	(0.12)		(0.36)	(0.21)	(0.12)	(19.85)
EU(15)	4.26	0.23	0.77	1.41		0.22		4.47	15.00	2.93	64.23
	(2.09)	(0.11)	(0.42)	(0.40)		(0.11)		(0.68)	(2.80)	(0.45)	(14.11)
India					4.55			0.94		5.90	17.68
					(6.83)			(0.67)		(4.23)	(18.48)
World total	39.96	36.64	14.51	19.62	16.67	10.15	14.00	26.50	25.44	23.28	433.04
	(29.35)	(26.59)	(10.45)	(14.35)	(17.39)	(6.53)	(5.46)	(10.64)	(4.99)	(8.83)	(269.45)
	10.61	10.05	4.06	5.27	-0.72	3.62	8.54	9.86	20.45	14.45	163.60

Note: Numbers without brackets reflect the amount that would be needed by the importing countries to produce the imported grains within their own territory. Numbers in brackets reflect the amount of water that the exporting country actually used to produce exported grain. The difference is the impact of trade on global water use. A positive number indicates that water use is reduced because of trade. A negative number implies an increase in water use because of trade.

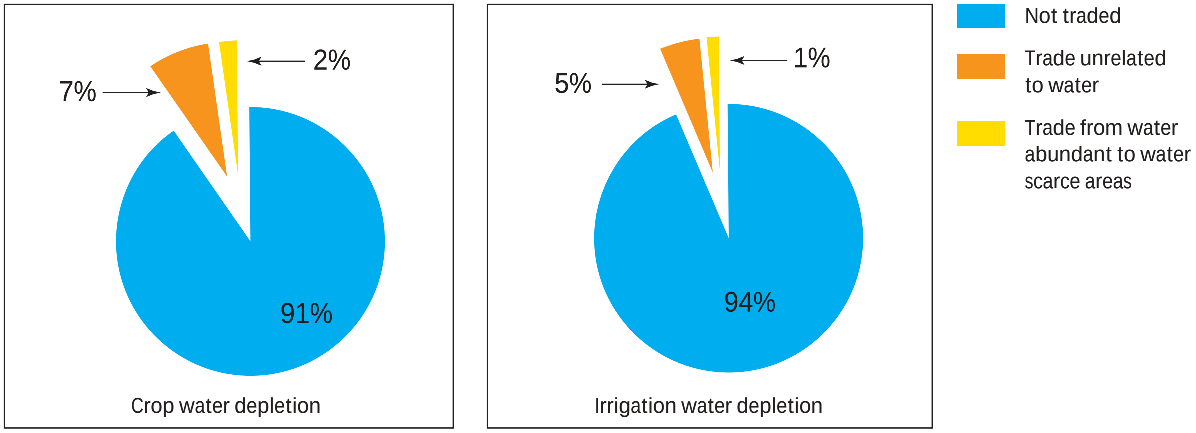
TABLE 6.

Virtual water flows between major cereal importers and exporters in 1995, measured in cereal irrigation water depletion (km^3).

Import/ Export	China	Japan	Korea Rep	Brazil	Indonesia	Egypt	Mexico	Iran	Algeria	Saudi Arabia	World total
USA	8.85	18.28	7.53	1.66	1.09	9.35	3.54	1.87	2.45	4.92	91.13
	(2.28)	(2.49)	(1.32)	(0.19)	(0.30)	(0.90)	(0.71)	(0.17)	(0.23)	(0.16)	(12.40)
Canada	1.34	2.60		0.98	0.03		0.09	1.33	0.11	6.55	17.94
	(0.15)	(0.15)		(0.05)	(0.00)		(0.01)	(0.05)	(0.00)	(0.09)	(1.12)
Argentina	0.12	0.56	0.26	5.46	0.38		0.11	0.06		0.38	12.56
	(0.03)	(0.06)	(0.04)	(0.53)	(0.09)		(0.02)	(0.00)		(0.01)	(1.42)
Australia	0.36	2.15	0.05	0.15	0.04	0.08		0.25	0.15	0.23	7.94
	(0.36)	(1.14)	(0.03)	(0.07)	(0.05)	(0.03)		(0.09)	(0.05)	(0.03)	(4.96)
EU(15)	1.54	0.15	0.45	0.67	0.02	0.21		1.40	4.68	2.58	22.60
	(0.18)	(0.01)	(0.04)	(0.04)	(0.00)	(0.01)		(0.06)	(0.20)	(0.04)	(1.23)
India					1.00			0.29		5.20	7.84
					(2.86)			(0.28)		(2.78)	(7.78)
World total	13.30	23.83	8.46	9.25	3.67	9.85	3.79	8.27	7.94	20.48	178.52
	(5.68)	(3.95)	(1.48)	(1.07)	(5.17)	(0.98)	(0.78)	(4.39)	(0.63)	(2.41)	(66.77)
	7.62	19.88	6.98	8.18	-1.50	8.87	3.01	3.88	7.31	18.07	111.75

Note: Numbers without brackets reflect the amount that would be needed by the importing countries to produce the imported grains within their own territory. Numbers in brackets reflect the amount of water that the exporting country actually used to produce exported grain. The difference is the impact of trade on global water use. A positive number indicates that water use is reduced because of trade. A negative number implies an increase in water use because of trade.

FIGURE 4.
Water depletion in global cereal production.



There is no linear relation between water scarcity, water productivity and water savings through trade (table 7). Major importers like Japan, Korea, Brazil and Indonesia are not water scarce. Some importers, such as Egypt, combine water scarcity and high water productivity. Here the lack of water resources in their territories may have played and will continue to play an important role in food imports, and thus global water savings. Importers that combine water scarcity with a low water productivity (such as Algeria, Pakistan and Iran) will increasingly face the choice between growing imports or the pressure to use water more productively.

Most major exporters “save” water because they export to countries that show a low water productivity relative to theirs. Australia forms an illustrative case. Although it uses irrigation to produce cereals for export, it still decreases global irrigation use because it uses irrigation water more efficiently than the countries to which it exports. Conversely, global water use is increased by exports from India to countries exhibiting a higher water productivity. These two cases illustrate the overriding importance of relative water productivity among importers and exporters, in assessing the water saving potential of trade. They provide evidence that water “savings” through trade are correlated more strongly to water productivity than to water scarcity.

In sum, the reduction in global water use occurs as an unintended by-product of cereal trade, occurring because most exporters are more water efficient than importers and produce under highly productive rain-fed conditions while importers would have relied on irrigation—at least partly. Water scarcity plays a minor role in shaping cereal trade flows, except for a few extremely water-short countries.

Time Series 1980–2000

An analysis based on one year may paint a misleading picture for some countries. For example, in the year 1995, China was a major importer of grains but in 2000 it exported 3 million tons. If the year 2000 had been chosen as a baseline year, the virtual map would have

TABLE 7.
Relation between water productivity and water savings through trade in 1995.

Major exporters	Crop water reduction (km^3)*	Irrigation depletion reduction (km^3)	Crop water productivity (kg/m^3)**	Water scarcity***
USA	114.5	78.7	++	-
EU(15)	50.1	21.4	+++	-
Canada	15.7	16.8	++	-
Australia	4.4	2.9	+	+/-
Argentina	3.2	11.1	+	-
India	-0.6	-0.1	—	+
Selected importers				
Algeria	20.5	7.3	—	+++
Iran	15.7	3.9	—	+
Saudi Arabia	14.4	18.1	—	+++
Japan	10.0	11.8	+	-
China	7.6	7.4	=	+
Pakistan	5.5	6.6	—	++
Korea Rep	4.1	6.9	=	-
Egypt	3.6	8.7	+	+++
World total	154	112		

Notes: * For example, without trade from the USA global water use would have been 114 km^3 higher. A negative number means an increase: the cereal exports from India increased global crop water depletion by 0.6 km^3

** Water productivity relative to world's average. "+" means higher; "-" means lower; and "=" means more or less equal to world's average.

*** Water scarcity: "- "no water scarcity, "+" partly, water scarce "+++" high water scarcity.

looked different. An analysis of trends over the past 20 years adds interesting insights. The resulting 21 maps (one for each year) are not reproduced here but will be incorporated in IWMI's Water and Climate Atlas.[12]

Because of data limitations, the time series analysis is not as detailed as in the base year. Except for the base year, no information is available on irrigation water use and effective precipitation. Because of the lack of time series data, crop evapotranspiration over the period 1980–2000 is approximated by the long-term average. Furthermore, no distinction could be made between irrigated and rain-fed production modes.

Cereal Trade Pattern

While global cereal trade increased from 180 million tons in the early 80s to 240 million tons in 2000, the general *export* pattern remains more or less equal, with the USA, Canada, Australia, Argentina and Europe as major exporters. The *import* pattern fluctuates from year to year and by country. China, India, Pakistan and South Africa are importers in some years and exporters in others. Although large in absolute quantities, India's and China's imports and exports consist of only a small percentage of domestic cereal production and consumption. In the period 1996–2000 China's net trade is less than one percent of total cereal production.

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[12] Website: http://www.iwmi.cgiar.org/WAtlas/atlas.htm

Impact of Trade on Water Use

The volume of crop water that the exporters depleted to produce exported grains remained more or less stable at around 270 km^3. The amount of water that the importers would have used otherwise fluctuated between 400 and 550 km^3. Consequently, the reduction of water use because of trade varied from 150 to 250 km^3, showing a slight upwards trend (figure 5). Since the trade pattern did not change, the observed trends are mostly explained by relative water productivity differences between importers and exporters. On average, water productivity improved steadily over the past 20 years, but in exporting countries at a higher rate than in importing countries, thus widening the productivity gap (figure 6). Despite growth in cereal exports, the amount of crop water depleted remains stable, because the growth is offset by productivity improvement in exporting countries.

This time series analysis shows that an increase in cereal trade volume does not necessarily translate in an increase in virtual water flows. Over the past 20 years cereal trade volume grew by one third, while the volume of virtual water trade remained at the same level and "savings" through trade increased only slightly. The major factor here is the relative difference in water productivities between importers and exporters.

Projection for the Year 2025

Are the current patterns and the importance of virtual water in global water use likely to change? To gauge the future role of cereal trade in global water use, an estimate is made for the year 2025, based on the projections by the IMPACT-WATER model. The model and underlying assumptions are described in Rosegrant et al. (2002). Compared to other forecasts, the model foresees a substantial increase in global cereal trade according to its Business-as-Usual scenario. In the period 1995–2025, the cereal trade volume will increase by nearly 60 percent to from 214 to 345 million tons in 2025 (figure 7). The overall trading pattern—i.e., major importers and exporters —will remain similar to the base year, with the USA, the European Union, Canada, Australia and Argentina as major exporters, mainly producing under rain-fed conditions. China, Japan, Korea, Indonesia, Egypt, Mexico and Iran still figure among the top 10 importers as in the base year, but are now joined by India (table 8).

Rosegrant et al. (2002) foresee that in 2025 the world will produce 2,615 million tons of grains, for which 2,981 km^3 of crop water will be depleted (corresponding to 0.88 kg/m^3). The cereal export will rise to 343 million tons for which the exporters will deplete 336 km^3, corresponding to 1.02 m^3 per kg, an improvement of 24 percent compared to 1995.

Trade and Water Savings

Although trade volume is forecasted to grow by 60 percent, crop water depletion by exporters, being offset by productivity growth, will increase by only 20 percent to 336 km^3 (11% of total). Despite the growth in traded volume, irrigation water depletion for exported cereals remains more or less the same at 65 km^3 (6% of total), because of predicted productivity improvements in irrigated agriculture. Global crop water "savings" through trade more than doubles from 164 to 359 km^3 while the irrigation water "savings" rise by 70 percent from 111 to 191 km^3 (tables 9 and 10). The latter implies that, in 2025, without trade irrigation, depletion would be 19 percent higher than with trade. "Savings" are

FIGURE 5.
Virtual water trade (cereals) for the period 1980-2000.

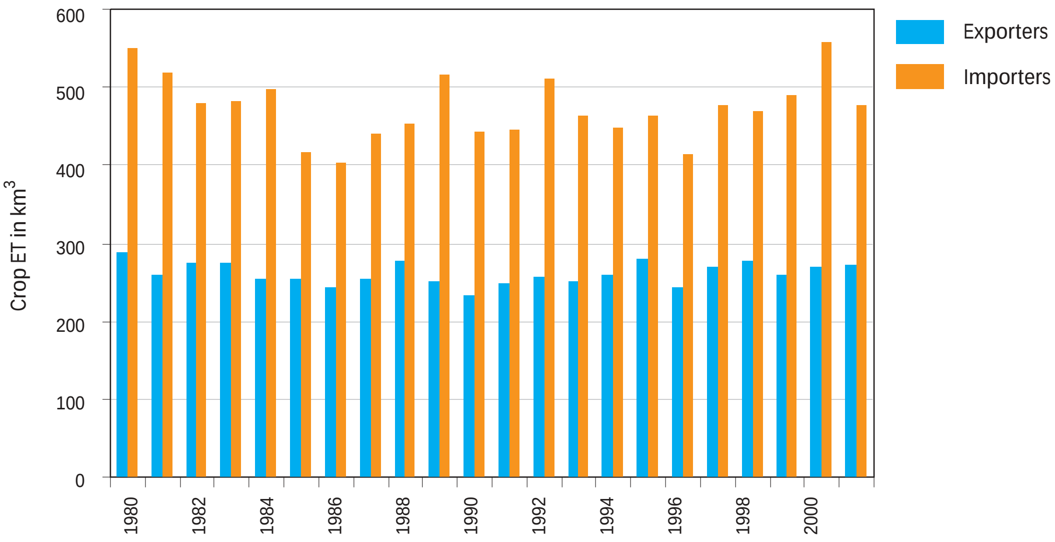


FIGURE 6.
Water productivities of exporters and importers, 1980-2000.

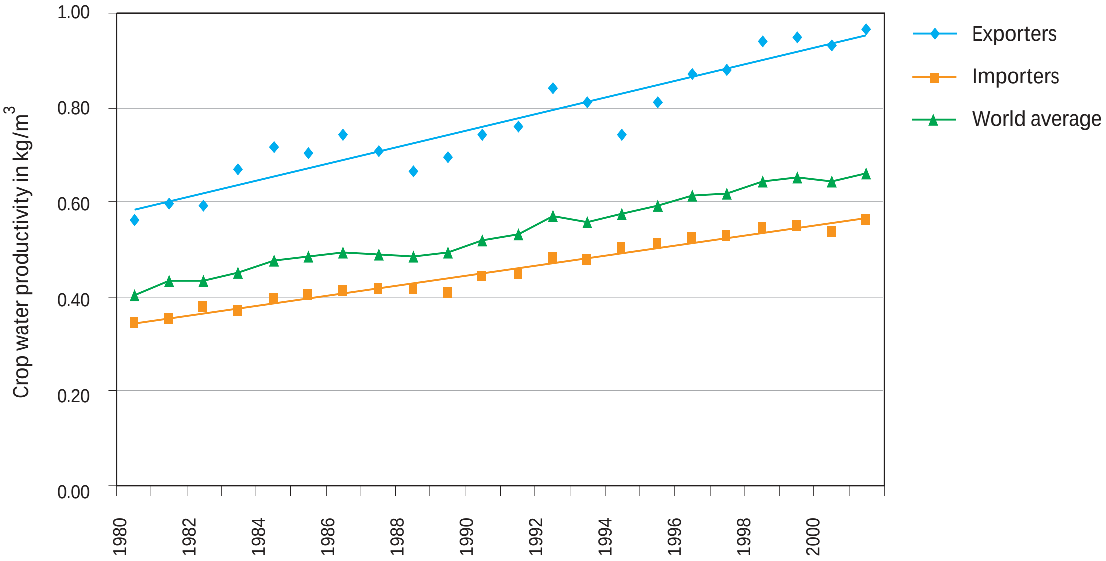
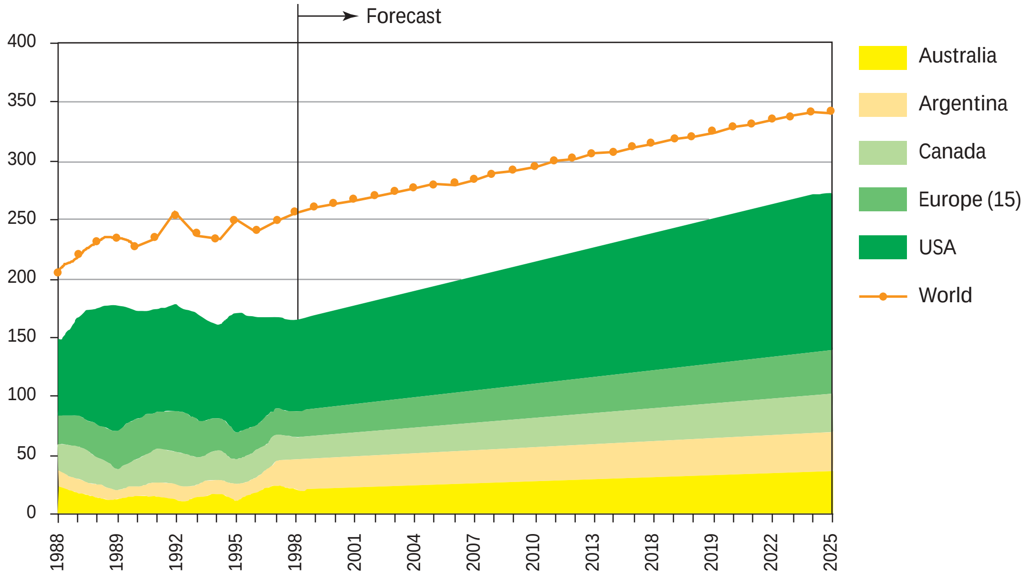


FIGURE 7.
Global cereal trade, observed and forecasted, in million tons.



Source: Observed data are taken from FAOstat database forecasts by IMPACT-WATER model (Rosegrant et al. 2002).

higher than in 1995 because the trade volume increases and the water productivity in exporting countries is forecasted to grow at a higher pace than in importing countries.

In view of increasing global scarcity (Seckler et al.1998), the role of water scarcity in trade is likely to increase. Following the method described earlier about 38 percent of the cereal trade in 2025 may be water scarcity related. The major part of the cereal trade volume is—and will continue to be—unrelated to water scarcity issues.

It is important to stress that this analysis is based on one of the many possible trade scenarios. Other predictions may differ in trade volumes and patterns. For example, China's wheat production may be affected by the rapid decline of the groundwater table in many of the wheat growing areas. Because China is the world's largest wheat producer, this may affect world market prices and trade flows. To what extent water scarcity will affect China's ability to sustain its agricultural production, is subject to debate. Nevertheless, compared to other forecasts (such as by Seckler et al. 1998 and 2000) the IMPACT-WATER Business-as-Usual scenario foresees a substantial growth in trade. It is thus safe to conclude that, even with substantial increases in trade, the role of water scarcity in virtual water trade is likely to remain relatively small in the coming decades.

TABLE 8.

Bilateral cereal trade flows in 2025 (million tons).

Importer/ Exporter	China	Japan	Saudi	Korea Rep	India	Mexico	Egypt	Brazil	Iran	Indonesia	Pakistan	Other	World total
USA	34.05	20.73	3.98	10.93	2.66	13.23	11.08		0.13	2.34	0.33	37.91	*137.37*
Australia	0.13	1.74		4.15	5.45		1.74		3.68	4.90	0.44	14.63	*36.86*
Canada	5.12	3.23	1.04	0.91		1.81	0.23	0.15	3.33	1.74	0.02	17.33	*34.91*
Argentina	0.22	0.88	1.15	2.19	0.18		1.53	12.16	2.12	0.10		13.28	*33.81*
Europe (15)	1.42	0.27	7.32	0.23			0.35		1.06			18.03	*28.68*
Russian Fed			3.13		0.89				0.39		1.21	9.99	*15.61*
Bulgaria					2.88						3.82	4.24	*10.94*
Hungary					1.56						2.08	5.49	*9.13*
Vietnam					0.02					1.65		6.05	*7.72*
Other	0.02	2.13	3.19	1.34	4.81	0	0	0.90	0.65	0.14	2.46	12.52	*28.15*
World total	40.96	28.98	19.81	19.75	18.45	15.03	14.93	13.21	11.36	10.87	10.36	139.47	343.18

TABLE 9.
Virtual water flows between major cereal importers and exporters in 2025, measured in cereal crop water depletion (km³).

Import/ Export	China	Japan	Saudi Arabia	Korea Rep	India	Mexico	Egypt	Brazil	Iran	Indonesia	World total
USA	17.65	19.62	6.13	8.84	27.98	23.96	7.56	0.39	0.97	4.86	244.56
	(12.25)	(12.73)	(1.23)	(5.33)	(7.81)	(9.47)	(5.56)	(0.14)	(0.17)	(2.05)	(85.10)
Canada	10.60	3.11	1.88	2.28	2.82	0.40		2.03	12.74	1.03	59.48
	(10.58)	(3.26)	(0.61)	(2.23)	(1.27)	(0.25)		(1.18)	(3.59)	(0.71)	(34.93)
Argentina	1.44	1.21	2.23	1.86	0.54		1.43	18.10	5.65	1.67	65.90
	(2.18)	(1.72)	(0.98)	(2.01)	(0.33)		(1.98)	(14.30)	(2.16)	(1.54)	(45.86)
Australia	5.71	2.66	0.19	5.35	5.33		2.83		16.47	4.87	67.30
	(5.92)	(2.45)	(0.08)	(5.45)	(2.98)		(3.01)		(5.74)	(4.12)	(45.64)
EU(15)	0.52	0.43	13.19	0.25	0.29		0.41	0.11	5.28	0.35	86.62
	(0.32)	(0.24)	(2.32)	(0.13)	(0.07)		(0.27)	(0.04)	(0.81)	(0.13)	(15.64)
World total	36.57	28.59	28.29	19.25	47.40	25.08	12.59	22.69	47.27	15.93	694.60
	(35.63)	(23.31)	(7.56)	(17.52)	(21.21)	(10.34)	(12.86)	(17.55)	(15.99)	(11.90)	(336.54)
	0.94	5.28	20.73	1.73	26.19	14.74	-0.27	5.12	31.28	4.03	358.06

Note: Numbers without brackets reflect the amount that would be needed by the importing countries to produce the imported grains within their own territory. Numbers in brackets reflect the amount of water that the exporting country actually used to produce exported grain. The difference is the impact of trade on global water use.

TABLE 10.

Virtual water flows between major cereal importers and exporters in 2025, measured in cereal irrigation water depletion (km^3).

Import/ Export	China	Japan	Saudi Arabia	Korea Rep	India	Mexico	Egypt	Brazil	Iran	Indonesia	World total
USA	8.09	10.91	6.12	4.51	11.75	6.45	6.93	0.18	0.26	0.90	88.51
	(1.83)	(1.91)	(0.18)	(0.80)	(1.17)	(1.42)	(0.83)	(0.02)	(0.03)	(0.31)	(12.74)
Canada	4.86	1.73	1.87	1.16	1.18	0.11		0.94	3.43	0.19	23.78
	(0.48)	(0.13)	(0.02)	(0.09)	(0.05)	(0.01)		(0.05)	(0.14)	(0.03)	(1.40)
Argentina	0.66	0.68	2.22	0.95	0.23		1.31	8.40	1.52	0.31	25.78
	(0.11)	(0.09)	(0.05)	(0.12)	(0.02)		(0.12)	(0.72)	(0.11)	(0.08)	(2.30)
Australia	2.62	1.48	0.19	2.73	2.24		2.60		4.43	0.90	27.50
	(1.98)	(0.86)	(0.02)	(1.61)	(0.74)		(1.04)		(1.43)	(1.01)	(11.40)
EU(15)**	0.24	0.43	13.15	0.13	0.12		0.38		1.42		32.79
	(0.03)	(0.02)	(0.18)	(0.01)	(0.01)		(0.02)		(0.06)		(1.24)
Total world	16.76	12.00	28.20	9.82	19.90	6.75	11.45	10.53	12.72	2.94	255.79
	(4.76)	(3.74)	(1.31)	(2.96)	(4.39)	(1.59)	(2.18)	(1.28)	(3.49)	(2.46)	(64.36)
	12.00	12.16	26.89	6.86	15.51	5.16	9.27	9.25	9.23	0.48	191.42

Note: Numbers without brackets reflect the amount that would be needed by the importing countries to produce the imported grains within their own territory. Numbers in brackets reflect the amount of water that the exporting country actually used to produce exported grain. The difference is the impact of trade on global water use.

Conclusions and Discussion

Virtual water trade potentially reduces water use at two levels: national and global. Because it takes between 500 and 4,000 liters of crop water to produce one kilo of cereal, a nation reduces water use substantially by importing food instead of producing it on its own soil. At the global level, water savings through trade occur if production by the exporter is more water efficient than by the importer. Trade reduces irrigation water use when the exporting country cultivates under rain-fed conditions, while the importing country would have relied on irrigated agriculture.

Does Cereal Trade Save Water?

At first sight, the potential of trade to “save” water—at national and global level—is substantial. At the national level, all importers combined “saved” 433 km^3 of crop water and 178 km^3 of irrigation water by importing cereal—which quantity of water would otherwise have been depleted for producing cereal domestically. At the global level, cereal trade reduced water use by 164 km^3 of crop water and 112 km^3 of irrigation water depletion. In other words, without trade, crop and irrigation water depletion for cereals would have been higher by 6 percent and 11 percent, respectively. And, as trade volumes are expected to grow, it is likely that these amounts will increase during the coming decades. Based on trade forecasts by Rosegrant et al. (2002), by the year 2025 cereal trade may reduce irrigation water depletion by 191 km^3. In other words, without trade, irrigation water depletion in 2025 may be 19 percent higher.

These numbers, summarized in table 11, suggest that cereal trade “saves” large quantities of water at country and global level and probably will continue to do so. But the conclusion that trade plays a prominent role in global water conservation may be misleading.

TABLE 11:
Cereal production and global water use, summary table.

1995	Million tons	km^3 of ET	km^3 of irrigation
Global production	1,724	2,875	979
Total traded*	215		
Depleted by exporters		269	67
‘Saved’ by importers		433	179
‘Savings’ because of trade		164	112
Trade related to water scarcity	52	64	15
2025 projection based on Rosegrant et al. (2002)			
Global production	2,615	2,981	1,013
Total traded*	343		
Depleted by exporters		337	64
‘Saved’ by importers		695	256
‘Savings’ because of trade		358	191
Trade related to water scarcity	130	128	24

Note: *Excludes trade within the European Union.

Real and Virtual Water Savings

The positive impact of trade on the global water use (or “savings”) occurs due to two reasons: 1) major exporters produce more efficiently with water than major importers, and 2) major exporters produce under highly productive rain-fed conditions, while most importers would have relied—at least partly—on irrigation.

Though trade has the potential to reduce global water use, it is incorrect to equate “virtual” flows to “real” water savings. The following nuances should be kept in mind:

1. Reductions in global water use because of trade relate to productivity differences between importers and exporters rather than water scarcity issues. They are an unintended by-product, or positive externality, of international trade in agricultural commodities.

2. Most trade occurs and will continue to occur for reasons unrelated to water. At present, less than a quarter of the cereal trade volume occurs from water-abundant to water-short areas. Despite increasing global water shortages in the coming 30 years (Rosegrant et al.2002), the analysis in this report suggests that in 2025 more than 60 percent of cereal trade will occur for reasons unrelated to water.

3. Where trade occurs for water scarcity related reasons, the importing countries often have few options other than to import. It is thus misleading to argue that Egypt (for example) “saves” water by imports. They do not have these water resources in the first place, and reduced imports would mean starving or fewer Egyptians.

4. Where water productivity is low, water-short importing countries will increasingly face the choice between growing imports or the pressure to use water resources more productively. In most importing countries there is still ample scope to conserve water by increasing “crop per drop.”

5. Productivity improvements in irrigated and rain-fed areas may play a more prominent role in water conservation than trade. For example, according to IWMI’s global water use projections (Seckler et al. 2000), improvements in “crop per drop” will reduce global water use by 1,205 km^3 during the period 1995–2025, compared to 355 km^3 because of trade. Forecasts by Rosegrant et al. (2002) yield similar results.

6. It is essential to distinguish between rainfall and irrigation water. In global cereal production most of total crop water originates from effective precipitation (66%) as opposed to irrigation (34%). “Savings” of in-situ precipitation cannot be automatically reallocated to other uses, besides natural vegetation or alternative rain-fed crops. Only when trade results in a reduction of *irrigation* water depletion, is it proper to speak of “real” water savings. From an environmental view, this is not always positive. Global irrigation water savings because of trade may be coming at the price of natural environments in rain-fed countries.

7. Reductions in water use are only beneficial if “saved” water can be reallocated to other uses (including environmental purposes). This may not always be the case in paddy growing areas in Asia during the monsoon. Because of the combination of abundant rain, floods and limited storage capacity, there is no alternative use to water that would be “saved” by importing paddy rather than growing it.

8. This study yielded no evidence that countries consciously use trade as a tool to conserve their own water resources because of environmental concerns. Political considerations on food security seem to outweigh environmental concerns.

Virtual Water as a Policy Tool?

A growing number of researchers suggest that international food trade can be used as an active policy instrument to mitigate local and regional water scarcity. Rather than striving for food self-sufficiency, water-short countries should import food from water-abundant countries. Trade in virtual water as an answer to water shortages and further environmental degradation is appealing. Allan (2001) refers to virtual water trade as an “economically invisible and politically silent” tool to reduce water scarcity.

But there are several factors that need to be considered. As the recent WTO talks in Cancun illustrate, the economical and political interests associated with agricultural trade are enormous. Is it realistic to assume that countries will change trade policies because of emerging global water scarcity issues? Will possible adverse affects of imports on national rural economies and food security, especially in poor countries vulnerable to fluctuations in world market prices, be outweighed by the benefits of reduced pressure on water resources? These questions are still wide open.

Extreme water-short countries in the Middle East have no option other than to import food. Others, facing the tradeoff between increased pressure on water resources and imports, are often wary of depending on imports to meet basic food needs. For countries such as China and India—with large, growing populations and increasing water problems—food self-sufficiency is still a national priority. Moreover, the question remains whether the countries that will be hardest hit by water scarcity will be able to afford to import “virtual water.”

Although it is unlikely that water scarcity concerns will shape global trade flows, virtual water may gain in importance during the coming decades. Article 92 of the declaration issued by the 2002 World Summit on Sustainable Development states that agreements under the WTO should be evaluated on social and environmental impacts. In view of the adverse effects of intensive irrigated agriculture on nature, monitoring virtual water flows associated with agricultural trade will be an essential part of such an evaluation.

Suggestions for Further Analysis

The results and conclusions of the analysis presented in this report are sensitive to the values of crop water productivity. Yet, estimates on water productivity and efficiency measures vary considerably by source, and datasets often lack consistency. For this study, estimates on yields and values of effective efficiency, precipitation and crop evapotranspiration are taken from Rosegrant et al. (2002) and IWMI’s Water and Climate Atlas. Because reliable estimates are essential for the discussion on virtual water and global water use, the estimation of water productivity deserves a separate study, beyond the scope of this report.

The present analysis is based on cereals because reliable data on bilateral trade flow available from FAOstat do not include other crops. Cereals may be an adequate indicator of food production and trade in the Asian region, but it is not representative for the African region where roots and tubers provide a large part of the staple food. Furthermore, because the analysis is based on cereals, some countries may be depicted as virtual water importers, while in fact, they are net water exporters. For example, Brazil is a major importer of cereals, but the quantity of soybean exports exceeds cereal imports. Taking soybean production into the water use equation, Brazil would be a net exporter of water. When a consistent and recent global dataset on bilateral trade flows of all agricultural commodities becomes available, it is worthwhile to extend the study accordingly.

Finally, because no reliable and consistent information on bilateral trade flows is available, this study makes use of Minimum Cross Entropy (MCE) principles. Although this method has proven to give good results in other applications, uncertainty remains on the accuracy of the MCE estimates.

Annex: Minimum Cross Entropy to Estimate Bilateral Flows

Why Entropy Optimization?

Data on actual bilateral cereal trade flows are available from existing databases, such as FAOstat. However, they are not always consistent. For example, the sum of bilateral flows reported in the FAOstat database "export of cereals by source and destinations" do not add up to the total import and export flows reported in the FAOstat database "agriculture and food trade."[13] It is reasonable to assume that data on total imports and exports are more reliable than bilateral flows, because totals are easier to monitor than individual flows and reported bilateral flows may be incomplete. The question then is how to reconcile the inconsistencies between both data sources while making optimal use of the available information. This analysis makes use of the Bayesian statistical technique called Minimum Cross Entropy.

Entropy optimization is based on the Probability and Information Theory developed by Shannon (1948a and 1948b). Jaynes (1978) and Golan et al. (1996) generalized these principles for use in parameter estimation. Entropy-based estimation methods are now used in a wide range of applications in physics, biology, topography, engineering, communication, operation research, economics, pattern recognition and image reconstruction (Kapur and Kesavan 1992). They are particularly useful when data are incomplete, aggregated or inconsistent (Golan et al. 1996).

Minimum Cross Entropy

The two most important entropy optimization principles, relevant to parameter estimation, are Maximum Entropy (Jaynes 1957a and 1957b) and Minimum Cross Entropy. The Minimum Cross Entropy (MinxEnt) formalism, first developed by Kullback and Leibner in 1951, minimizes the "probabilistic distance" between the data and the prior information, while consistent with the constraints posed by the actual observations. The objective of MinxEnt is to find, out of all the distributions of probabilities satisfying the constraints, the one closest to the prior information (Golan et al. 1996). The general formulation of Minimum Cross Entropy is:

$$\min I\,(p,q) = \sum_{i=1}^{n} p_i \ln(p_i / q_i) \sum_{i=1}^{n} = p_i \ln p_i - \sum_{i=1}^{n} p \ln q_i \qquad (1)$$

$$\text{subject to } \sum_{i=1}^{n} p_i = 1 \text{ and observations} \qquad (2)$$

where I = cross entropy (or probabilistic distance) to be minimized
p = parameters values to be estimated
q = prior information

The analysis in this report uses incomplete and inconsistent data on bilateral trade flows as prior information. The reliable observations on total trade from and into countries are reflected in the constraints.

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[13] Available from websites http://apps.fao.org.

Based on the general formulation by Kapur and Kesavan (1992), the following Minimum Cross Entropy model is employed:

Prior information on bilateral and total trade flows in a particular year is given by:

$$\sum_i \sum_j T_{i,j} = T0 \tag{3}$$

where

$T_{i,j}$ = bilateral trade from country i to j
$T0$ = total of all export flows.[14]

Totals of trade flows from and into a certain geographical unit and projected global totals are given by:

$$\sum_j X_{i,j} = EXP_i \tag{4}$$

$$\sum_i \sum_j X_{i,j} = EX \tag{5}$$

with

$X_{i,j}$ = unknown bilateral trade flow from country i to j
EXP_i = observed or forecasted total export from country i
EX = observed or forecasted total projected global exports

$T_{i,j}$ is given by FAOstat database as "cereal trade by destination." This data is considered incomplete and not consistent with the totals. EX_i is given by FAOstat as "agricultural commodity trade" for 1995 and by the results of IMPACT/PODIUM for 2025. This data is considered as reliable. Because information on future bilateral flows is not available, forecasts for 2025 use bilateral flow information of the year 2000 as prior information.

The unknown bilateral trade flows, $X_{i,j}$, is found by minimizing cross entropy:

$$\min H = \sum \sum \frac{X_{i,j}}{EX} .1\text{n} \frac{X_{i,j} / EX}{T_{i,j} / TO} \tag{6}$$

subject to (3), (4), (5)

The objective function given by equation 6 implies that all countries exporting did so in the previous years also. To avoid this problem and allow for changes in trading patterns, Kapur and Kesavan (1992, p. 191) suggest the following measure:

$$\min H' = \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{X_{i,j} + c}{T + cn^2} \; 1\text{n} \frac{(X_{i,j} + c) / (EX + cn^2)}{(T_{i,j} + c) / T0 + cn^2)} \tag{7}$$

where c is an arbitrary positive number.

In this analysis equation 7 is used subject to (3), (4) and (5).

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[14] The model assumes that global exports and imports balance out and $T_{i,j} \geq 0$.

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