PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

Phil. Trans. R. Soc. B (2006) **361**, 835–842
doi:10.1098/rstb.2005.1644
Published online 20 October 2005

Review

Virtual versus real water transfers within China

Jing Ma[1,*], Arjen Y. Hoekstra[2,3], Hao Wang[1], Ashok K. Chapagain[2] and Dangxian Wang[1]

[1]*Department of Water Resources, China Institute of Water Resources and Hydropower Research, No. 20 Chegongzhuang West Road, Haidian District, 100044 Beijing, China*
[2]*UNESCO-IHE Institute for Water Education, PO Box 3015, 2601 DA Delft, The Netherlands*
[3]*University of Twente, PO Box 217, 7500 AE Enschede, The Netherlands*

North China faces severe water scarcity—more than 40% of the annual renewable water resources are abstracted for human use. Nevertheless, nearly 10% of the water used in agriculture is employed in producing food exported to south China. To compensate for this 'virtual water flow' and to reduce water scarcity in the north, the huge south–north Water Transfer Project is currently being implemented. This paradox—the transfer of huge volumes of water from the water-rich south to the water-poor north versus transfer of substantial volumes of food from the food-sufficient north to the food-deficit south—is receiving increased attention, but the research in this field has not yet reached further than rough estimation and qualitative description. The aim of this paper is to review and quantify the volumes of virtual water flows between the regions in China and to put them in the context of water availability per region. The analysis shows that north China annually exports about 52 billion m^3 of water in virtual form to south China, which is more than the maximum proposed water transfer volume along the three routes of the Water Transfer Project from south to north.

Keywords: virtual water; trade; water transfer; water footprint; China

1. BACKGROUND

Over 50 years ago, Mao Zedong had a well-known saying: 'water abundance in the south and scarcity in the north; if possible we can borrow a little bit of water from the south to give to the north'. Research on the idea of transporting water from south to north China at a large scale started 50 years ago. Today, final plans have been drafted and elements of the south–north Water Transfer Project are being implemented. Indeed, north China is suffering from water shortage and relies on water transfer from the south to relieve the water crisis. However, at the same time, north China, as China's breadbasket, annually exports substantial volumes of water-intensive products to south China. This creates a paradox in which huge volumes of water are being transferred from the water-rich south to the water-poor north while substantial volumes of food are being transferred from the food-sufficient north to the food-deficit south. This paradox is receiving increased attention, but the research in this field is still at the stage of rough estimation and qualitative description, partly due to the absence of appropriate methodologies to address the issue.

In the early 1990s, Tony Allan introduced concept of 'virtual water' as a tool to describe the 'virtual' water flows exported from a region as a result of export of water-intensive commodities (Allan 1993). The aim of this paper is to quantitatively assess the virtual water flows between the regions in China and to put them in the context of water availability per region.

2. METHODOLOGY

(a) *General*

The water used in the production process of an agricultural or industrial product is called the 'virtual water' consumed in the product. In order to assess the virtual water flows between nations or regions, the basic approach has been to multiply the product trade volumes (ton yr^{-1}) by their associated virtual water contents. The virtual water content of crops has been estimated per crop per region on the basis of various Food and Agriculture Organization of the United Nations (FAO) databases (CropWat (http://www.sdnbd.org/sdi/issues/agriculture/database/CROPWAT.htm), ClimWat (http://www.fao.org/landandwater/aglw/climwat.stm), FAOSTAT (http://faostat.fao.org/)). The virtual water content of livestock products has been calculated along the lines of 'production trees' that show different product levels (Hoekstra 2003). This study has focused on the analysis of virtual water flows within China. Data on the virtual water flows between China and other nations have been taken from Chapagain & Hoekstra (2003) and Hoekstra & Hung (2003).

(b) *Method of assessing virtual water flows between regions in China*

Net import of food into a region (or net export from the region) is a function of regional production, stock changes and domestic utilisation. In this study we draw

* Author for correspondence (majing_06@yahoo.com.cn).

Received 24 September 2004
Accepted 1 March 2005

Table 1. FAO food balance sheet. (Source: FAO (2004).)

	domestic supply (DS)					domestic utilization (DU)						*per capita* supply (SPC)			
													per day		
	production	import	stock change	export	total	feed	seed	processing	waste	other use	food	kg yr^{-1}	calorie	protein	fat
product	metric ton												no.	gr.	gr.
c	P	I	ΔS	E	T	Fd	Sd	Pro	Wa	Ou	Fo				

regional food balances using the same definitions as in the food balance sheets of the FAO (2004); see table 1. Net import into a region is thus given by:

$$\mathrm{NI}(n_i, t, c) = \mathrm{DU}(n_i, t, c) - \mathrm{P}(n_i, t, c) - \Delta\mathrm{S}(n_i, t, c), \quad (2.1)$$

where $\mathrm{NI}(n_i, t, c)$ denotes the net import of importing region n_i in year t as a result of trade of product c, $\mathrm{DU}(n_i, t, c)$ is the total domestic utilisation (by definition equivalent to total domestic supply), $\mathrm{P}(n_i, t, c)$ is the production of product c, and $\Delta\mathrm{S}(n_i, t, c)$ is the stock change. The net virtual water import related to trade in product c, $\mathrm{NVWI}(n_i, t, c)$, is equal to the net import volume of product c multiplied by its virtual water content $\mathrm{VWC}(n_e, t, c)$ in the exporting region n_e:

$$\mathrm{NVWI}(n_i, t, c) = \mathrm{NI}(n_i, t, c) \times \mathrm{VWC}(n_e, t, c). \quad (2.2)$$

(c) *Regional delimitation*

The research area in this paper is mainland China excluding Hong Kong Special Administrative Region, Macao Special Administrative Region and Taiwan Province. It consists of 31 provinces, municipal cities and autonomous regions. In line with the traditional regional delimitation, the country is first schematized into two regions, i.e. north and south. Both north and south are further divided into four sub-regions. Each sub-region consists of three to five provinces (table 2).

(d) *Research scope and assumptions*

As 70% of the total water withdrawal is used in agriculture, we focus in this study on agricultural products. We have classified these products into six categories: 'grain', 'vegetable', 'fruit', 'meat and poultry products' (hereafter 'meat'), 'egg and related products' (hereafter 'egg') and 'milk and dairy products' (hereafter 'dairy product'). The analysis has been carried out with data for the year 1999, when China experienced a normal hydrological year, but a good year in terms of harvest.

The paper is based on the following assumptions:

- (i) No change in product storage over the year.
- (ii) Agricultural products imported from outside China are targeted to the provinces with production deficits and are distributed in proportion to the deficit per province.
- (iii) Agricultural products exported from China to other nations come from provinces with production surplus.
- (iv) After accounting for international trade, the sub-regions with deficits import agricultural products from the closest neighbouring sub-regions with surplus.

3. VIRTUAL WATER FLOWS WITHIN CHINA

(a) *Virtual water content per product category per region*

The virtual water content is first calculated separately for 25 kinds of crops, six kinds of meat and for eggs and milk. Calculations are done per province. Consequently, the average virtual water content for each of

Table 2. Chinese regional delimitation.

region	sub-region	provinces
north China	north-central	Beijing, Tianjin, Shanxi
	northeast	Inner Mongolia, Liaoning, Jilin, Heilongjiang
	Huang-huai-hai	Hebei, Henan, Shandong, Aihui
	northwest	Shannxi, Gansu, Qinghai, Ningxia, Xinjiang
south China	southeast	Shanghai, Zhejiang, Fujian
	Yangtze (the area of middle and lower reaches of Yangtzi River)	Jiangsu, Hubei, Hunan, Jiangxi
	south-central	Guangdong, Guangxi, Hainan
	southwest	Chongqing, Sichuan, Guizhou, Yunnan, Tibet

Table 3. Virtual water content of six agricultural product categories by region ($m^3\ kg^{-1}$).

region	grain	vegetable	fruit	meat, poultry and related products	egg and related products	milk and dairy products
north	1.1	0.1	1.1	7.8	4.3	1.9
south	0.9	0.1	0.8	5.7	4.3	1.9
national average	1.0	0.1	1.0	6.7	4.3	1.9

the six categories of agricultural products is calculated based on a production-weighted average of the virtual water content of the various products per category. The results are summarized in table 3. In general, the virtual water content of products from north China is higher than in those from south China.

Two factors influence the virtual water content of crops: crop water requirement and crop yield. Crop water requirement is calculated from the accumulated crop evapotranspiration (Hoekstra & Hung 2003). The virtual water content of an animal and livestock product consists of three parts: virtual water from feeding, drinking and servicing (Chapagain & Hoekstra 2003). Correspondingly, the virtual water content of animal and livestock product also relies strongly on the virtual water content of crop. North China (except for part of the northeast) is arid or semi-arid area. The aridity index value (the ratio of potential evaporation to precipitation) is greater than 3 or even greater than 7 in some areas in the northwest. Conversely, south China is humid or semi-humid area. Abundant sunshine and strong evaporation in the north with a similar yield to the south causes the virtual water content of agricultural product to be higher in north China than in south China.

(b) *Food trade within China*

south China was the country's 'breadbasket' in the past. There was a saying "After harvest both in Hunan and Hubei, the whole country will have sufficient". However, this situation has changed since the early 1990s. In 1999 north China produced 53% of the total national grain, 57% vegetable, 55% fruit, 48% meat, 71% egg and 82% dairy product. Conversely, the consumption in south China of those agricultural products all exceeded 50% of the national total.

What was it that caused the 'breadbasket' to change of from south China to north China? First, south China—especially south-central and the southeast, where the Reform & Open Policies were initially implemented—is densely populated, and the richest area of the country. Huge investment has resulted in manufacturing prosperity and the construction of infrastructure that occupies substantial areas of fertile land. Consequently, the nature of the workplace has shifted from agricultural to secondary and tertiary industries. Second, improvements in living standards have caused a dietary change resulting in the consumption of more agricultural products. The subsequent huge increase in food demand has stimulated the farmers' enthusiasm in areas such as the northeast, Huang-huai-hai, where the fertile land, sunshine and heat provide good conditions for improving food production. Also, the national food policy—keeping food self-sufficiency at a high level—determines that a new 'breadbasket' should be established to substitute for the old one in order to feed the country's huge population. This shifting has also caused the current situation in which virtual water and real water inversely flow between the north and south within China.

At a national level, China can currently realize a balance between food production and demand. However, at the regional level, north China has a food surplus area and south China a food deficit. As to the eight sub-regions, the areas of food surplus include the northeast and Huang-huai-hai in north China and Yangtze in south China. The other five regions have food deficits, of which in some densely populated and developed areas such as north-central, southeast and south-central, the deficit accounted for more than 20% of their total demand.

Chapagain & Hoekstra (2003) showed that, in 1999, China made a net import of grain and dairy products, and a net export of vegetables, fruit and meat. Disregarding international trade, south China imported 17 million tons of grain, 23 million tons of vegetables, 0.6 million tons of fruit, 1.8 million tons of meat, 2.3 million tons of egg and 2.4 million tons of dairy product from north China (see table 4 for details).

Table 4. Food trade in China in 1999 ($\times 10^6$ ton).

	region	grain	vegetables	fruit	meat	egg	dairy products
net import from other nations[a]	north	−4.2	−2.3	−0.3	−0.2	−0.01	0.00
	south	4.5	−0.1	0.1	0.1	0.00	0.12
	national total	0.3	−2.4	−0.2	−0.1	−0.01	0.12
net import from other region	north	−17.1	−23.2	−0.6	−1.8	−2.3	−2.4
	south	17.1	23.2	0.6	1.8	2.3	2.4

[a] Based on Chapagain & Hoekstra (2003).

Table 5. Virtual water imports and exports by region (10^9 m^3).

	from other region within China			from outside China				
	gross virtual water import from north	gross virtual water import from south	net virtual water import	gross virtual water import	gross virtual water export	net virtual water import	overall net virtual water import	net virtual water import *per capita*
north	—	−51.6	−51.6	8.4	16.2	−7.8	−59.4	−102
south	51.6	—	51.6	19.7	2.7	17.0	68.6	104
national total	—	—	0	28.1	18.9	9.2	9.2	7

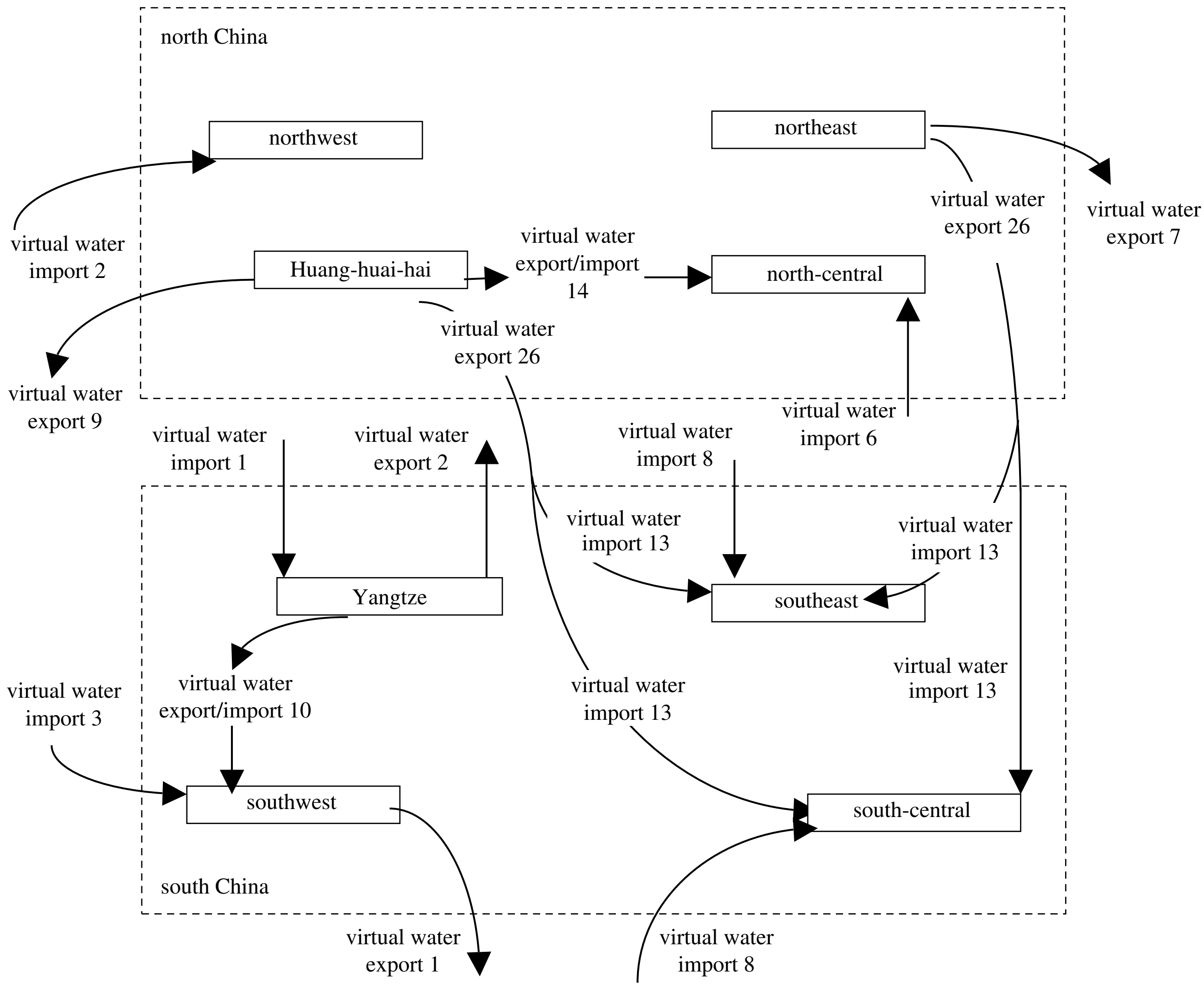

Figure 1. Virtual water transfers in China (10^9 m^3 yr^{-1}).

Table 6. Water footprint by region in 1999.

region	use of domestic resources: blue water: surface water (10^9 m^3 yr^{-1})	ground water (10^9 m^3 yr^{-1})	sub-total (10^9 m^3 yr^{-1})	green water (10^9 m^3 yr^{-1})	total (10^9 m^3 yr^{-1})	net virtual water import (10^9 m^3 yr^{-1})	water footprint (10^9 m^3 yr^{-1})	water footprint *per capita* (m^3 yr^{-1})	water self-sufficiency (%)
north-central	5.5	7.0	12.5	26.6	39.1	20.4	59.5	1092	66
Huang-huai-hai	56.4	33.9	90.3	255.4	345.7	−48.7	297.0	954	100
northeast	49.1	23.0	72.1	122.9	195.0	−32.3	162.7	1253	100
northwest	68.7	12.4	81.1	45.6	126.7	1.2	127.9	1425	99
north	179.7	76.3	256.0	450.5	706.5	−59.4	647.1	1106	100
Yangtze	118.1	5.9	124.0	116.6	240.6	−10.7	229.9	960	100
southeast	48.4	1.1	49.5	25.9	75.4	33.5	108.9	1176	69
south-central	74.2	3.7	77.9	41.2	119.1	33.8	152.9	1199	78
southwest	49.4	2.9	52.3	101.1	153.4	12.0	165.4	837	93
south	290.1	13.6	303.7	284.8	588.5	68.6	657.1	999	90
national total	469.8	89.9	559.7	735.3	1295.0	9.2	1304.2	1049	99

(c) *Virtual water flow between regions in China*

China as a whole had a positive virtual water balance, with a net import of virtual water in 1999 of 9 billion m^3, which means around 7 m^3 *per capita*. The gross import was 28 billion m^3, with most virtual water going to the south. The gross export was 19 billion m^3, with the major share originating from the water-scarce north. The virtual water flow from north to south was around 52 billion m^3 (table 5). The various virtual water flows between the eight sub-regions are shown in figure 1.

4. WATER FOOTPRINT AND WATER SELF-SUFFICIENCY BY REGION

Hoekstra & Hung (2003) defined the water footprint of a nation or region as the use of domestic (internal) water resources (WU) plus the use of foreign (external) water resources (net virtual water import). By analogy to the ecological footprint, the water footprint can be a strong tool to show the impact of consumption on the natural resources. Total internal water use, here, includes both blue water (referring to the use of surface and ground water) and green water use (referring to the use of infiltrated precipitation). The use of foreign (external) water resources is a function of the volume of water used abroad to produce the goods imported. In this paper we have just calculated external water for imported food produced with water abroad.

$$\text{Water footprint} = \text{WU} + \text{NVWI}. \quad (4.1)$$

Furthermore, an index of water self sufficiency (WSS) is calculated as follows:

$$\text{WSS} = \begin{cases} \dfrac{\text{WU}}{\text{WU}+\text{NVWI}} \times 100 & \text{if NVWI} \geq 0, \\ 100\% & \text{if NVWI} < 0. \end{cases}$$

Water self-sufficiency denotes a nation's ability to supply its own water needs for domestic demand and for goods and services. Self-sufficiency is 100% if all the water needed is available within the own country or region. Water self-sufficiency approaches zero if a country or region heavily relies on virtual water imports.

In 1999 China had a water footprint of 1304 billion m^3 yr^{-1}. north and south China had an equal share (table 6). The average water footprint *per capita* in China was 1049 m^3 yr^{-1}. This is quite near to the global average water footprint, which is 900 m^3 yr^{-1} *per capita* (according to Rockström & Gordon (2001), total global water use is 5400 billion m^3 yr^{-1}, while the world population amounts to 6 billion). It is, however, much lower than the water footprint *per capita* in countries such as the USA, Italy and Spain, where footprints *per capita* are more than two times higher.

The people in north China transform 707 billion m^3 yr^{-1} of their real water budget of 2115 billion m^3 yr^{-1} into virtual water (figure 2). Together with the import of virtual water from abroad, the annual virtual water budget of north China amounts to 715 billion m^3 yr^{-1}. The part of this virtual water budget which is consumed within north China, 647 billion m^3 yr^{-1}, constitutes north China's water footprint. The remainder, 68 billion m^3 yr^{-1}, is being exported to south China and abroad. south China transforms only 588 billion m^3 yr^{-1} of their real water budget of 4073 billion m^3 yr^{-1} into virtual water. They achieve a water footprint of 657 billion m^3 yr^{-1} by having substantial virtual water imports from north China and abroad.

At a national level, China had very high water self-sufficiency of 99% in 1999. At a regional level, the water-scarce north had a 100% self-sufficiency, whereas the water-rich south relied on virtual water import, having a water self-sufficiency of only 90%.

From blue water withdrawal constitution we can see that ground water accounted for 30% in north China, which already approached 95% of its ground water storage. Figure 2 also shows the situation in which the ground water in north China was heavily extracted.

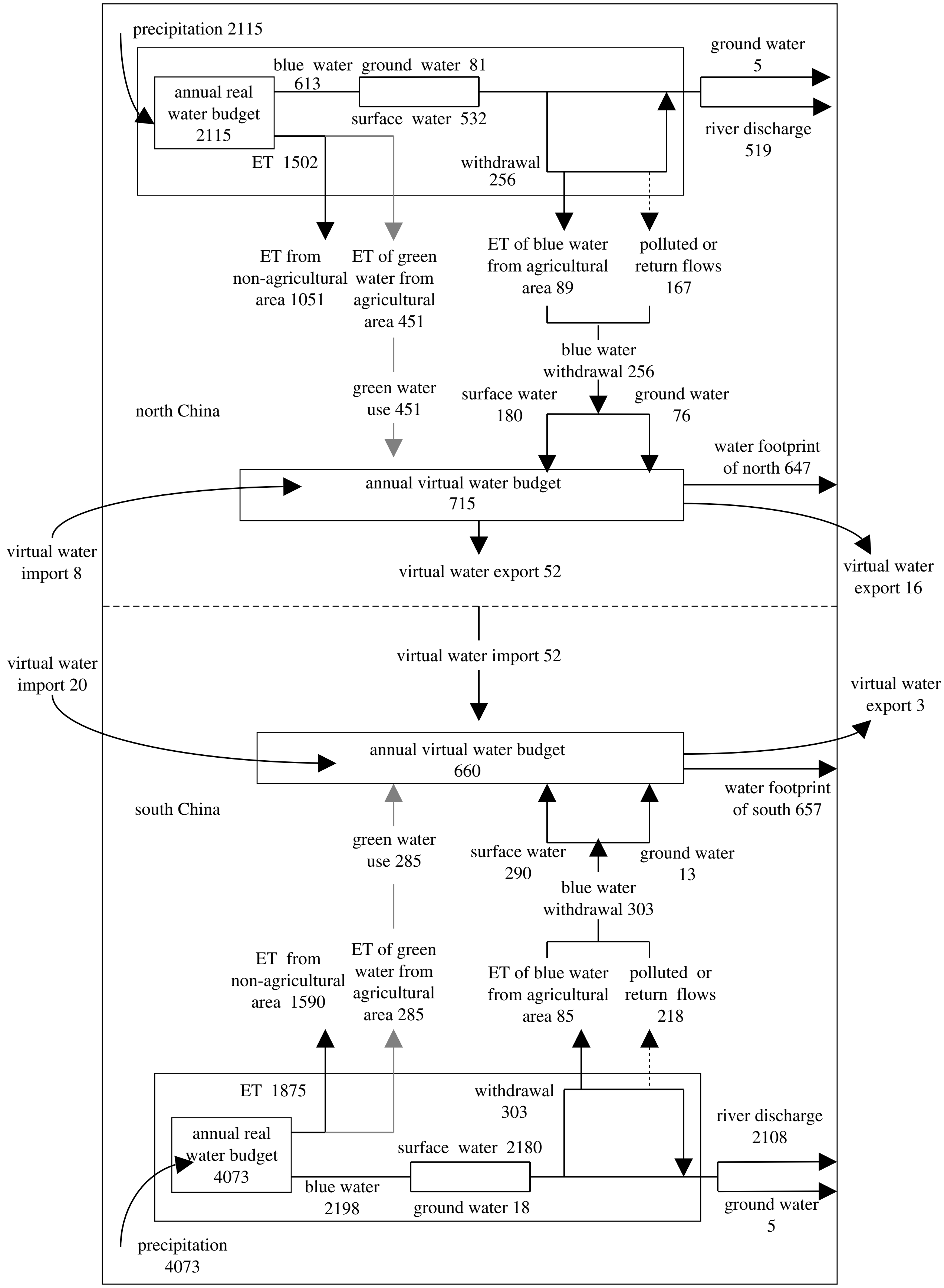

Figure 2. Real water balance and virtual water balance of north and south China (10^9 m^3 yr^{-1}). (Note: ET is a formal abbreviation of evapotransporation in hydrology.)

China experienced a normal year in 1999. Naturally the water balance in figure 2 is based on a multi-annual average value instead of the value during the dry period. Although there has been a severe water crisis in north China since the 1990s, a lot of rivers located in remote areas are still virgin territories even now, whose water accounts for a huge share of annual renewable water availability. The paper only focuses on the water

Table 7. Virtual water import and water availability of sub-regions in China in 1999.

	net virtual water import within China (10^9 m^3 yr^{-1})	net virtual water import from outside China (10^9 m^3 yr^{-1})	net virtual water import (10^9 m^3 yr^{-1})	net virtual water import *per capita* (m^3)	water availability *per capita* (m^3)
north-central	14.1	6.3	20.4	375	369
Huang-huai-hai	−39.9	−8.8	−48.7	−157	532
northeast	−25.8	−6.5	−32.3	−249	1568
northwest	0.0	1.2	1.2	14	2487
north	−51.6	7.8	−59.4	−102	1047
Yangtze	−10.2	−0.5	−10.7	−45	1821
southeast	25.8	7.7	33.5	361	2976
south-central	25.8	8.0	33.8	265	3143
southwest	10.2	1.8	12.0	61	5496
south	51.6	17.0	68.6	104	3347
national total	0	9.2	9.2	7	2234

quantitative balance. If the water quality were also taken into account, water that can be balanced should be deducted. Furthermore, this paper assumes the return flow reaches the river channel directly and neglects recharging of ground water. Therefore, the river discharge, 519 billion m^3, looks far too optimistic given the finding that the runoff of river in north China has decreased by approximately 20–50% since the 1990s and the drying up of rivers seems increasingly serious from the findings reported by Brown & Halweil (1998), Ren *et al.* (2001) and Suo (2004).

5. VIRTUAL WATER IMPORTS AND EXPORTS IN RELATION TO WATER AVAILABILITY

(a) *Virtual water import and water availability*

With further analysis of net virtual water import per sub-region, one interesting finding is that the higher the *per capita* water availability in a sub-region, the larger the volume of virtual water import (table 7). Huang-huai-hai, for instance, has a population of 310 million and a water availability of 550 m^3 per person per year, which is even less than in the Middle East and north Africa, where 300 million people use the limited water supplies with a *per capita* share of 900 m^3 yr^{-1} (Berkoff 2003). Nevertheless, virtual water export from this region, which is regarded as one of the most water-scarce territories in the world, is quite substantial. Huang-huai-hai exported 49 billion m^3 of water in virtual form in 1999, which is 157 m^3 per person per year.

What is behind the phenomena? As water is of vital importance to agriculture, logically, just from the perspective of water, virtual water export should be proportional to the water availability. In China one can find the reverse situation. Apparently other factors than water—probably availability of fertile land in particular—have been determinants of the process which has led to the current situation. Even today, the approach is mainly supply-oriented. Although concepts of demand management have long been promoted, they are in practice hardly applied.

(b) *North–south virtual water flows in relation to the south–north Water Transfer Project*

The Water Transfer Project from south to north is the biggest inter-basin water transfer in the world. After a 50-year study, three water diverting routes have been worked out, i.e. the west route, the middle route and the east route. They will divert water from the upper, middle and lower reaches of the Yangtze River, respectively, with a maximum transfer amount of 38–43 billion m^3 yr^{-1} (east route: 15 billion m^3; middle route: 13 billion m^3; west route: 10–15 billion m^3) to meet the increasing requirements of northwest and north China (Qian *et al.* 2002). The east and middle routes have already been constructed, covering seven provinces and the municipal cities of Beijing, Tianjin, Hebei, Henan, Shandong, Anhui and Jiansu.

In 1999 south China imported 52 billion m^3 virtual water from north China. This was more than the maximum water transfer volume by the three routes of the south–north Water Transfer Project. Furthermore, Huang-huai-hai, a recipient area of the east and middle routes, had a virtual water export of 26 billion m^3 to south China. Although the maximum transfer amount via the two routes is 28 billion m^3, it also includes the water supply to other provinces in different sub-regions such as Beijing, Tian and Jiangsu. If the water going to these other provinces is subtracted, the actual water supply to Huang-huai-hai will be much less than its virtual water export.

6. CONCLUSION

Inter-basin water transfer can be realized either by real water transfers through massive engineering projects or by virtual water transfers in the form of commodities trade. In 1999, south China imported 52 billion m^3 of virtual water condensed in agricultural products from north China. The year 1999 was a normal year from a water resources perspective and a relatively good year from a harvest point of view. The virtual water volume exceeded the planned real water transfer volume of 38–43 billion m^3 yr^{-1} planned in the three south to north Water Transfer Projects.

The big question remains: is bringing the water from south to north in virtual form worth its environmental consequences? From a water resources point of view this does not make sense. There must be other decisive factors to justify the strategy. Factors that could play a role are availability of suitable cropland, possibly labour availability or national food security. A broader, integrated study would be required to give a more comprehensive assessment of the efficiency and sustainability of the south–north Water Transfer Projects.

The authors are grateful to the National Institute of Public Health and the Environment (RIVM), Bilthoven, the Netherlands, which sponsored the work underlying this paper.

REFERENCES

Allan, J. A. 1993 Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. In *Priorities for water resources allocation and management* (ed. Overseas Development Administration), pp. 13–26. London: Overseas Development Administration.

Berkoff, J. 2003 China: the south–north Water Transfer Project—is it justified? *Water Policy* **5**, 1–28.

Brown, L. R. & Halweil, B. 1998 China's water shortage could shake world food security. *World Watch Mag.* **11**, 10–21.

Chapagain, A. K. & Hoekstra, A. Y. 2003 Virtual water trade: a quantification of virtual water flows between nations in relation to international trade of livestock and livestock products. In *Virtual water trade proc. int. expert meeting on virtual water trade—Value of water research report series No. 12* (ed. A. Y. Hoekstra), pp. 49–76. Delft: IHE.

FAO 2004 FAO Nutrition's data. See www.fao.org.

Hoekstra, A. Y. 2003 Virtual water trade between nations: a global mechanism affecting regional water systems. *Glob. Change News Lett.* **54**, 2–4.

Hoekstra, A. Y. & Hung, P. Q. 2003 Virtual water trade: a quantification of virtual water flows between nations in relation to international crop trade. In *Virtual water trade proceedings of the international expert meeting on virtual water trade—Value of water research report series No. 12* (ed. A. Y. Hoekstra), pp. 25–48. Delft: IHE.

Qian, Z. Y., Lin, B. N., Zhang, W. Z. & Sun, X. T. 2002 *Comprehensive report of strategy on water resources for China's sustainable development*, 1st edn. Beijing: China Water and Hydropower Press.

Ren, L. L., Zhang, W., Wang, M. R. & Li, C. 2001 Impacts of human activities on river runoff in north China. *J. Hohai Univ. Nat. Sci.* **29**, 13–18.

Rockström, J. & Gordon, L. 2001 Assessment of green water flows to sustain major biomes of the world: implications for future ecohydrological landscape management. *Phys. Chem. Earth B* **26**, 843–851.

Suo, L. S. 2004 River management and ecosystem conservation in China. *Proc. Ninth Int. Symp. on River Sedimentation*, Yichang, China, 18–21 October 2004, pp. 3–10. Yichang, China: Ministry of Water Resources. See http://www.irtces.org/old/irtces/report/9isrs/LishengSuo.pdf.